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SOME ASPECTS OF LOWER MANNVILLE SEDIMENTATION IN SOUTHEASTERN ALBERTA

I. Banerjee

1990

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Critical readers

D.A. Leckie
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Editor

J.M. MacGillivray

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P.L. Greener

Cartography and Word Processing units

Institute of Sedimentary and Petroleum Geology

Author's address

I. Banerjee
Geological Survey of Canada
Institute of Sedimentary and Petroleum Geology
3303-33rd Street N.W.
Calgary, Alberta T2L 2A7

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SOME ASPECTS OF LOWER MANNVILLE SEDIMENTATION IN SOUTHEASTERN ALBERTA

Abstract

Subsurface stratigraphy and sedimentology of the Lower Mannville subgroup, consisting of the Deville Formation and two units, the Cut Bank Sandstone and the Ostracode Zone, have been studied in an area extending from Townships 1 to 20 and Ranges 1 to 20 west of the Fourth meridian, in southeastern Alberta. Paleotopographic control of the Cut Bank Sandstone and the nature of the marine transgression during deposition of the Ostracode Zone are the two main aspects of this study.

The paleogeological map pattern on the sub-Mannville unconformity surface indicates the presence of a number of north-trending valleys and possibly also a south-trending one. An isopach "thick" axis of the Cut Bank Sandstone coincides with one of the paleovalleys (Cut Bank Valley) in the Taber area. Most of the paleovalleys, however, are not reflected in the sedimentary record.

The Cut Bank Sandstone, as defined in this study, refers to the entire interval below the Ostracode Zone and above the basal unconformity. It consists of two facies: 1. a scour-based, crossbedded, gravelly, medium to coarse grained sandstone (channel facies) occurring in linear belts, which could be paleovalley-fill; and 2. a contorted, bioturbated, fine grained sandstone (bay-lagoon? facies), which occurs in sheets. The facies relationship may indicate a gradual encroachment of the sea from the north and the east over a braidplain during the latter part of the Cut Bank Sandstone depositional period. The Ostracode Zone records a widespread transgression and, in one well, has yielded a diverse foraminiferal assemblage indicating open marine conditions. In other wells, the Ostracode Zone-Glauconitic Sandstone interval contains marine fossils (mainly dinoflagellates) and displays typical progradational sequences of sedimentary structures that record offshore, shoreface, foreshore, and backshore environments. Storm sedimentation units with hummocky cross-stratification (HCS) and graded beds of gravel occur in these sequences.

Data obtained from five measured cross-sections in the southern Foothills indicate a marine influence during deposition of the Calcareous Member (equivalent to the Ostracode Zone).

Age data obtained mostly from palynomorph assemblages indicate a Barremian to Aptian age for the Cut Bank, late Barremian to early Albian for the Ostracode Zone, and Aptian to Albian for the overlying Glauconitic Sandstone. The Ostracode Zone has been found to be diachronous.

Résumé

La stratigraphie et la sedimentologie souterrainnes du sous-groupe de Lower Mannville, composé de la formation de Deville et de deux unités, le grès de Cut Bank et la zone à ostracodes, ont été étudiées dans une zone qui s'étend sur les cantons 1 à 20 et les rangs 1 à 20, a l'ouest du quatrième méridien, dans le sud-est de l'Alberta. Le contrôle paléotopographique du grès de Cut Bank et la nature de la transgression marine au cours de la mise en place de la zone à ostracodes sont les deux principaux aspects de cette étude.

La représentation cartographique de la paléogéologie de la surface de discordance sub-Mannville indique la présence d'un certain nombre de valléesà direction nord et d'une vallee probable à direction sud. Un axe isopaque "épais" du grès de Cut Bank coincide avec l'une des paléo-vallées (vallée de Cut Bank) dans la zone de Taber. La plupart des paléo-vallées, cependant, ne sont pas représentees dans la colonne sédimentaire.

Le grès de Cut Bank correspond dans la présente étude à l'intervalle entier situé au-dessous de la zone à ostracodes et au-dessus de la discordance basale. Il est composé de deux faciès : 1) un grès de grain moyen à grossier, graveleux, à stratification entrecroisée et à base affouillée (faciès de chenal) formant des bandes linéaires qui pourraient être des matériaux de remplissage de paléo-vallées; et 2) un grès à grain fin bioturbé et déformé (faciès de baie et lagune?) formant des couches. Le lien entre les faciès pourrait indiquer un envahissement graduel de la mer par le nord et l'est au-dessus d'une plaine à chenaux anastomosés au cours de la dernière partie de la période de sédimentation du grès de Cut Bank. La zone à ostracodes contient des indices de transgression étendue et, dans un certain puits, on a recueilli un assemblage de foraminifères divers indiquant la présence de conditions de milieu marin ouvert. Dans d'autres puits, l'intervalle entre la zone à ostracodes et le grès glauconitique contient des fossiles marins (principalement des dinoflagellés) et comporte des séquences de progression vers la mer de structures sédimentaires mises en caractéristiques place en milieux extracôtier, d'avant-plage, de bas de plage et d'arrière-plage. On retrouve dans ces séquences des unités de sédimentation de tempête caractérisées par une stratification entrecroisée à aspect memelonné et des couches de gravier trié.

Les données recueillies dans cinq coupes établies dans le sud des contreforts indiquent que des conditions marines existaient pendant la sédimentation du membre calcaire (équivalent à la zone à ostracodes).

Les datations, établies surtout à partir d'assemblages de palynomorphes, indiquent que l'âge du grès de Cut Bank se situe entre le Barrémien et l'Aptien, celui de la zone à ostracodes entre le Barrémien supérieur et l'Albien inférieur et celui du grès glauconitique sus-jacent entre l'Aptien et l'Albien. La formation de la zone à ostracodes est diachrone.

INTRODUCTION

The Lower Cretaceous strata in southern Alberta constitute a northeast-tapering wedge of clastic sedimentary rocks deposited in a foreland basin (Porter et al., 1982) that received synorogenic detritus from the emerging Cordillera during the Columbian Orogeny. This clastic sequence is divided into several stratigraphic units. The lowermost stratigraphic unit of the sequence is known as the Blairmore Group in the Foothills outcrop belt, and as the Mannville Group in the subsurface of the Interior Plains. The Mannville Group extends eastward to the edge of the Canadian Shield and outcrops in northeast Alberta, Saskatchewan and Manitoba (where it is known as the Swan River Group) along a northwest-trending, narrow outcrop belt that forms the erosional edge of the sedimentary prism.

Precise dating of various parts of the Blairmore–Mannville Group has not been possible due to lack of index fossils. Recent studies by Pocock (1980) on dinoflagellate assemblages from the Lower Mannville Formation indicate an early to late Aptian age. Foraminiferal fauna of the Moosebar tongue lying on top of the Gladstone Formation (equivalent to the Lower Mannville) indicate an age of late early Albian (McLean and Wall, 1981). The Joli Fou Shale overlying the Mannville Group is characterized by the *Haplophragmoides gigas* Zone (Mellon and Wall, 1963) indicating an early late Albian age. Presumably, then, the topmost beds in the Mannville Group must be middle Albian. Recently, Burden (1983) extended the base of the Mannville as far back as late Valanginian on the basis of palynomorphs.

Although the name Mannville is retained throughout, the nomenclature of the subdivisions within the group differs considerably between southern, central and northern Alberta, the Lloydminster area and southwestern Saskatchewan. Also, the stratigraphic nomenclature of the Blairmore Group in the Foothills outcrop belt is different from that used in the Peace River area (Stott, 1968). This semantic maze in the nomenclature of the Mannville Group is a direct consequence of the environmental complexities of the whole sedimentary package through time and space.

Glaister (1959) and Mellon (1967) presented regional overviews of the stratigraphy and sedimentation of the Blairmore–Mannville Group in Alberta. Their works have been followed by more local studies: by Williams (1963) in central Alberta, by Carrigy (1967, 1971) in the Athabasca area, and by Norris (1964) in the Crowsnest area where he described an undisturbed section of the Blairmore Group and proposed it as a principal reference section. McLean (1980) studied the northward facies change of the Blairmore Group into the Bullhead and Fort St. John's groups of the Peace River area. Hayes (1982a, b; 1983; 1986) studied the southward changes of the Blairmore–Mannville Group into Montana, where it is known as the Kootenai Formation. To the east, the Mannville Group of Saskatchewan has been studied by Price (1963), Maycock (1967), Christopher (1974, 1980), and Vigrass (1977).

In southern Alberta, local, detailed studies of the Mannville Group have been done more recently by Hopkins et al. (1982) in the Little Bow area, James (1982a, b, 1985) in southwestern Alberta, Farshori (1983) and McCoy and Moritz (1982) in the Countess oil field, and Tilley and Longstaffe (1984) in the Suffield area. Hayes (1986) recently published his work on the Lower Mannville stratigraphy in southeastern Alberta and Montana, an area which includes a part of the present study area (Fig. 1). Taylor and Walker (1984) made a sedimentological study of the Blairmore Group in the southern Foothills. Regional stratigraphic syntheses and paleogeography of the Mannville Group in Alberta and northeastern British Columbia have been presented by Jackson (1985) and Smith, Zorn and Sneider (1985). Preliminary results of the present study were reported elsewhere (Banerjee, 1983a, b, c, 1984).

An area encompassing 400 townships (Townships 1-20 and Ranges 1-20W4) has been chosen for this study (Fig. 1) and more than 500 geophysical logs and 95 lithology logs from the Canadian Stratigraphic Services, 728 well logs from the datafile of the Energy Resources Conservation Board of Alberta, and examination of approximately 150 cores form the database. Thin section petrographic studies of the rock, and paleoecological and biostratigraphic interpretation of paleontological data from more than 100 samples supplement the above database. Five measured outcrop sections of the Blairmore Group in the southern Foothills provide additional data.

Specific objectives of the present study were to document two basic features of Lower Mannville sedimentation in southern Alberta. The first was to locate incised paleovalleys filled with fluvial sediments on the sub-Mannville unconformity surface. The second was to document, from sedimentological and paleontological data, the Ostracode marine transgression, which signalled the end of Lower Mannville sedimentation in southern Alberta.

To locate paleovalleys, a paleogeological map of the sub-Mannville unconformity surface and an isopach and a facies map of the Lower Mannville strata have been used. Geophysical logs and cores of the sediments infilling these valleys were also studied. In the southern end of the area studied, one deeply incised paleovalley filled with multiple-scoured, coarsely crossbedded sandstone has been located.

Sufficient paleontological and sedimentological data have been collected to establish that marine conditions existed

Figure 1. *Location map showing study area, lines of cross-section of Figures 2, 5 and 6, and the outcrop belts of the Blairmore and Mannville groups.*

during deposition of the strata comprising the Ostracode Zone. A brackish water influence during deposition of the upper part of the Cut Bank Sandstone is also indicated. In two examples, a typical progradational sequence straddles the Ostracode Zone–Glauconitic Sandstone boundary. In this sequence, the Ostracode Zone represents the offshore deposits, the Glauconitic Sandstone represents the offshore-shoreface transition, the foreshore, and the backshore, and the overlying strata represent the coastal swamp and lagoon environments. Regionally, the same transgression-regression event has been documented in the southern Foothills (Taylor and Walker, 1984), in the central Alberta Plains (Wanklyn, 1985), and in Montana (Burden, 1983).

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D.A. Leckie and A.P. Hamblin critically read the present manuscript and made many useful suggestions for improvement. D.W. Gibson critically read an earlier version. The author also benefitted from numerous discussions held with Leckie, Gibson and other colleagues. Micropaleontology and palynology were done by J.H. Wall, D.J. McIntyre of the Geological Survey of Canada and E.H. Davies of the Bujak Davies Group.

REGIONAL STRATIGRAPHY

The correlation diagrams shown in Figure 2 illustrate the broad stratigraphic relationships and nomenclature of the Mannville strata in southern Alberta and their affiliations with adjoining strata in Alberta, Montana and Saskatchewan. Both diagrams show that the limestone-bearing horizon, known as the Calcareous Member in the outcrop belt and the Ostracode Zone in the subsurface, is a persistent regional marker in the area and is the most useful unit for correlating isolated cross-sections.

The north-south (Fig. 2A) and east-west (Fig. 2B) transects of the Lower Cretaceous strata have been compiled from the works of Williams (1963) in central Alberta, Glaister (1959) and Hayes (1986) in southern Alberta, Price (1963) and Christopher (1974) in southwestern Saskatchewan, and Walker (1974) in Montana.

The stratigraphic status of various units is far from well established. The status of the Mannville Group is accepted universally. The two subdivisions, named Lower and Upper Mannville formations by Glaister (1959), are also widely used. However, as the same name cannot be applied both to a group and a formation, the names proposed by Glaister defy the stratigraphic code and cannot be given a formal status. To eliminate this difficulty, some authors (Vigrass, 1977; Putnam and Oliver, 1980) have given an informal subgroup status to the Lower and Upper Mannville strata. This usage is followed here. As a consequence, the lowest hierarchy of subdivisions, which include existing, widely used units such as the Ellerslie and Sunburst members, the Ostracode Zone (Calcareous Member) and the Glauconitic Sandstone, should, ideally, be formations under this scheme. Although these units have mostly been described as members in the literature, they are distinct, subsurface, mappable units and may very well be considered as formations. However, the nomenclature used for the Mannville Group in Southern Alberta by earlier workers (Fig. 3) has varied so much over the years that no consensus is possible.

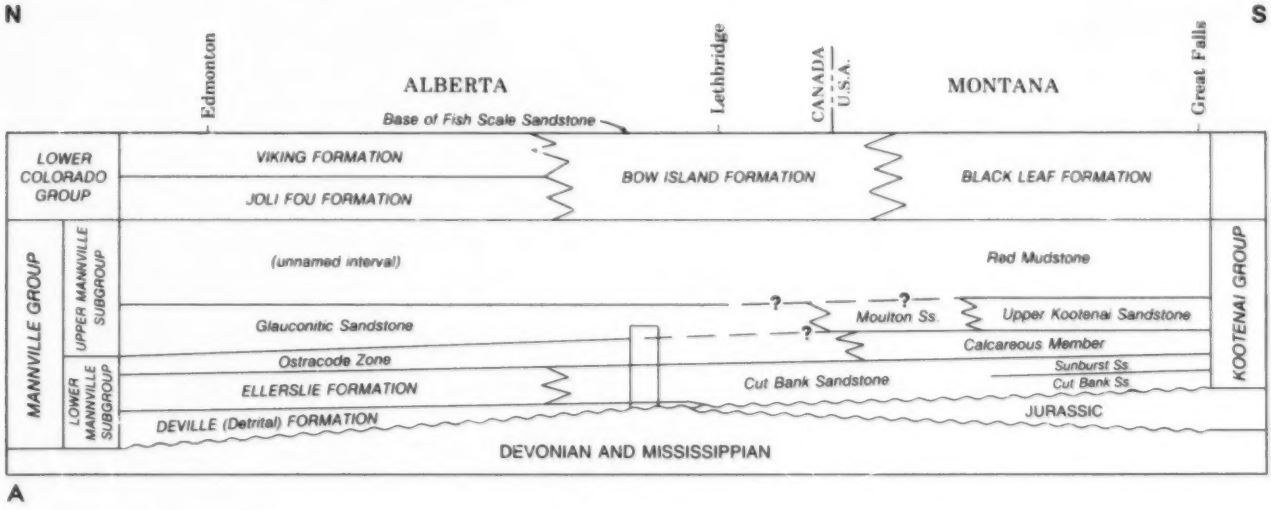
Because the state of stratigraphic nomenclature of the Mannville Group is in a state of continuing flux, the author does not propose to redefine or rename existing units. Terms such as the Cut Bank Sandstone or the Ostracode Zone will be used in this study as names reflecting established and current usage but without clearly defined status. The Lexicon of stratigraphic names of Western Canada published by the Alberta Society of Petroleum Geologists will be used as a rough guide of current usage (Lexicon, 1960). Where the Lexicon confers a formal status to a name such as the Deville Formation, this usage will be followed.

The Mannville Group thins moderately from 300 m in central Alberta to 100 m in the southern part of the province, and more markedly, from 900 m in the foreland basin in the southern Foothills in the west, to 100 m in the cratonic interior to the east (Fig. 2A, B).

The Lower Mannville subgroup within the study area, consists of the following three units, in descending stratigraphic order:

1. Ostracode Zone
2. Cut Bank Sandstone
3. Deville Formation

The correlation table in Figure 3 shows the full range of names used by earlier workers in the area for the Lower Mannville units, and their relationships to names in this study.



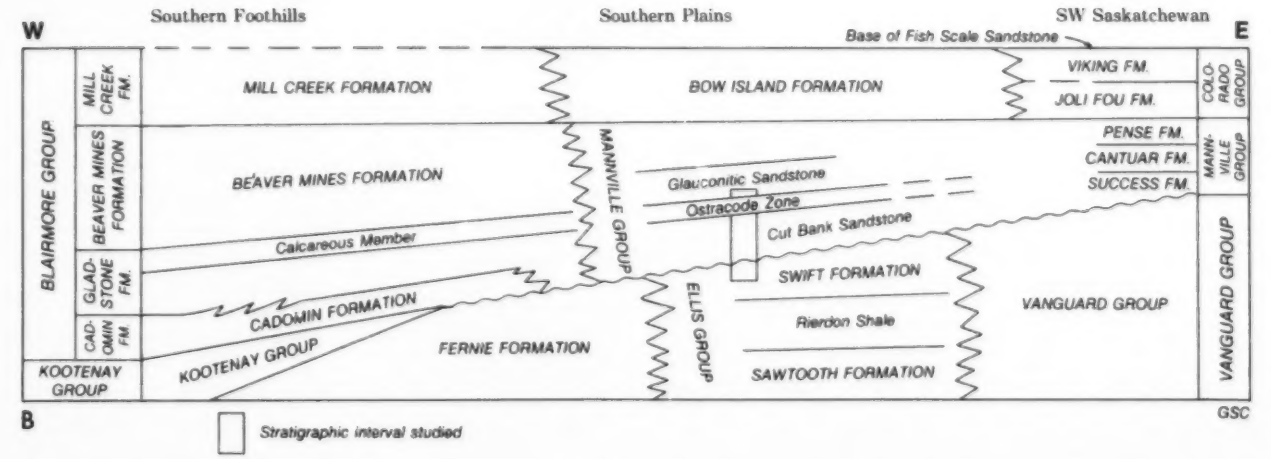


Figure 2. *The Mannville stratigraphy in the Alberta Plains is shown (A) in north-south and (B) east-west transects. A portion of the stratigraphy in the area studied is shown. Note the arbitrary vertical line separating the names Blairmore and Mannville. Compiled from various sources (see text).*

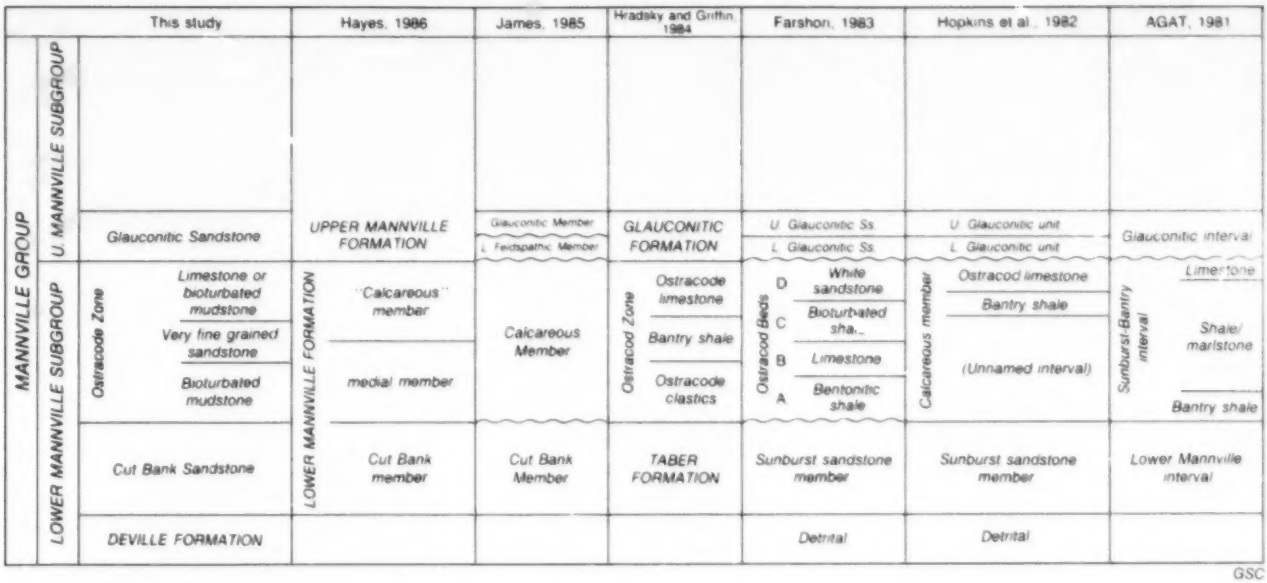


Figure 3. *Correlation table showing nomenclature of the Mannville stratigraphic units in the study area.*

Log expressions of these three units are illustrated in Figure 4. The Glauconitic Sandstone immediately overlies the Ostracode Zone and in many cases forms a continuous "coarsening-upward" sequence with it. Therefore, although not a part of the Lower Mannville subgroup, a brief description of this unit will be incorporated in this study. The Pre-Mannville formations, the three stratigraphic units of the Lower Mannville subgroup, and the Glauconitic Sandstone (Figs. 5, 6) will be described briefly in the following section.

PRE-MANNVILLE FORMATIONS

Immediately underlying the Lower Mannville, the rocks of the Jurassic Ellis Group are confined to the area approximately south of Township 11 (see Figures 2, 5, 8). The group consists of three formations, from top to base:

1. Swift Formation
2. Rierdon Shale
3. Sawtooth Formation

Sawtooth Formation

This formation is 15 to 18 m thick and immediately overlies the Mississippian carbonates and occurs at a few scattered subcrops (Figs. 5, 8). Typically the formation comprises an interbedded sequence of biomicritic limestone and very fine grained, well sorted glauconitic quartzarenite. Green or black shale interbedded with bioturbated, lenticular-bedded siltstone is also common. A 5 m thick, fine grained, ripple-laminated sandstone also occurs within the sequence.

Rierdon Shale

This is a widespread, sheet-like unit (Figs. 5, 8) 10 to 50 m thick, and consists of dark grey or black, splintery, pyritiferous shale. It may be correlated with the Fernie Formation in the Foothills.

Swift Formation

Hayes (1985) described in detail the stratigraphy of this unit in the study area. It is confined to two subcrops in the southeast and southwest (Fig. 8), and comprises a lower, lenticular bedded, bioturbated, very fine grained sandstone/mudstone unit called the "Ribbon Sand", and an upper grey shale unit that is glauconitic in places. It may be correlated with the Kootenay Group in the Foothills (Fig. 5).

All three Jurassic units disappear to the north of the area, where the Mannville is underlain directly by Mississippian rocks (Figs. 6, 8).

DEVILLE FORMATION

General

The name "Deville Formation" was formally proposed by Badgley (1952) with a designated type section in central

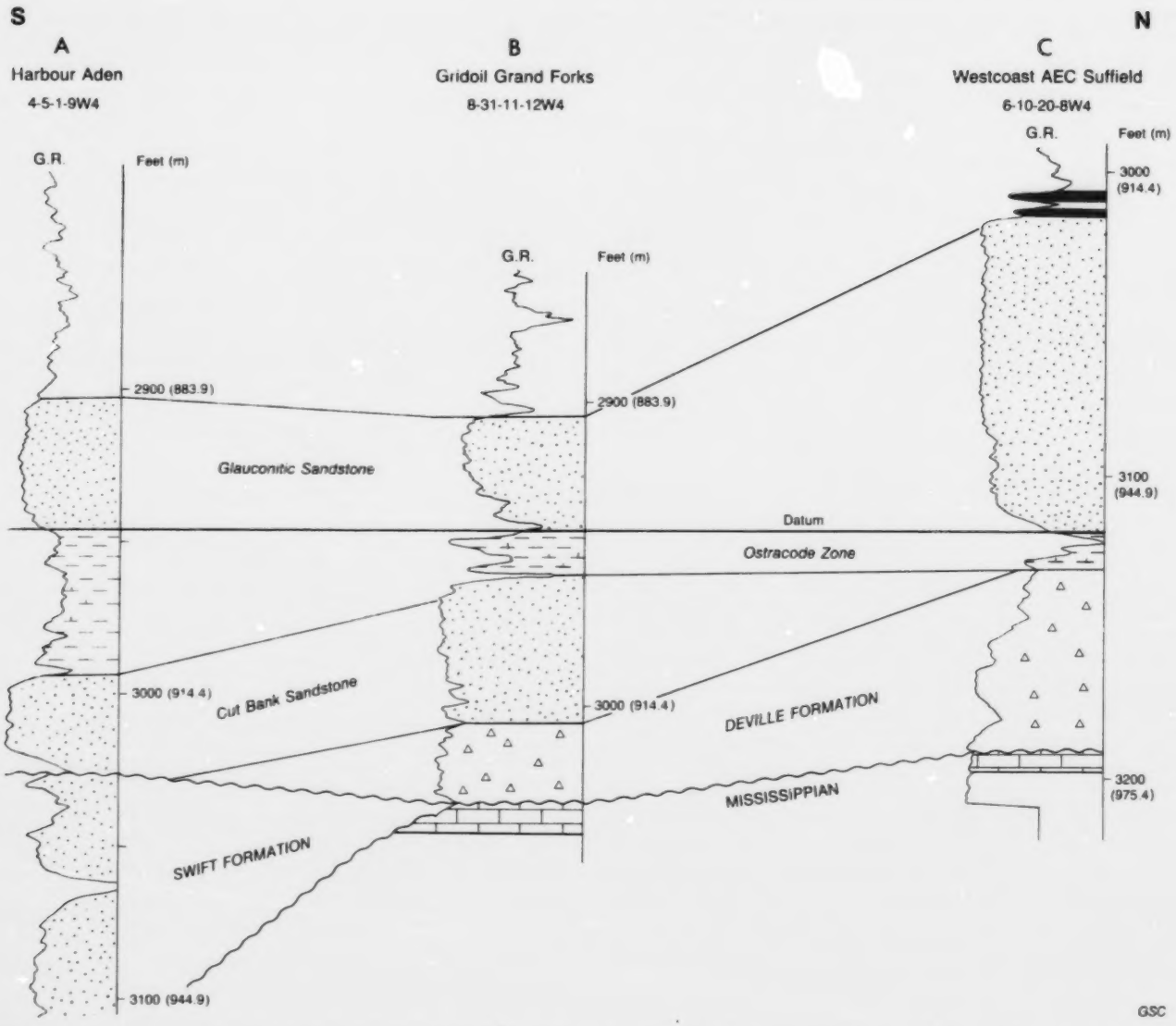


Figure 4. *Stratigraphic units and their relationships in the study area. Three representative well logs and cores from the south (A), middle (B) and north (C) ends of the area illustrate: 1. typical gamma-ray log expressions and lithologies of the units and 2. their stratigraphic relationships. Note: Deville Formation is absent over Jurassic rocks in (A), and present only over Mississippian rocks in (B) and (C). Also note the Ostracode Zone directly overlying the Deville in (C). For legend refer to Figure 10.*

Alberta, and his usage was followed in the Lexicon (1960). Although in southern Alberta the name "Detrital Zone" is more often used for the same unit, the term "Deville Formation" is preferred because Badgley (1952) intended specifically to replace the term "Detrital Zone" with "Deville Formation".

This unit is confined to the northern part of the area studied, between Townships 11 and 20, where the Mannville strata rest on the Mississippian carbonates (Figs. 6, 7). It gradually thins from a thickness of 20 m in Township 20 to 5 m in Township 11. It may underlie the Cut Bank sandstone or occur without the Cut Bank, directly underlying the Ostracode Zone (see Figures 4, 7). The most characteristic lithotype of this unit is a chert breccia, the angular chert fragments of which have been derived from the underlying carbonates and silicified *in situ*. Greenish, brownish, grey or black shales and medium to fine grained sandstones are also present in many sections. Its typical log expression is a blocky or "fining-upward" gamma-ray pattern.

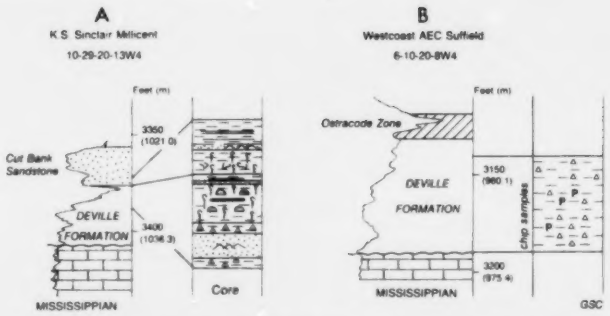


Figure 7. Two contrasting facies of the Deville Formation. For legend refer to Figure 10.

A. Lithologically diverse facies with a lower sandy and upper shaly part. The upper zone, containing bioturbated, pyritiferous, black shale, may have been subjected to some marine influence.

B. Lithologically homogeneous facies consisting of a thick (15 m) chert breccia with a mudstone matrix. It represents the weathered residue of the underlying carbonates.

Two contrasting lithological successions of the Deville Formation are illustrated in Figure 7. The thick, homogeneous chert breccia of one (Fig. 7B) contains angular chert clasts (1-5 cm in size) set in a brown or grey, silty matrix. The breccia shows no sedimentary structures that would indicate transportation, and contrasts sharply with the well bedded sequence of shale, crosslaminated sandstone and thin chert breccia beds of the second lithological succession (Fig. 7A). Pyrite is ubiquitous in both examples, occurring as disseminations, nodules or pyritized shells. The chert clasts in both instances are fragments of silicified fossiliferous limestones.

The lenticular bedding and bioturbation seen in the second lithological succession indicate quiet water and slow sedimentation; the crosslaminae in the sandstones reflect some current activity.

Petrography

Petrographic examination of the chert breccia reveals two distinctive textures:

1. A poorly sorted, medium grained, thick, lithic wacke with angular chert and argillite clasts, a few well rounded quartz grains, and spots of pyrite indicating subsequent pyritization.

2. A well sorted, fine grained sandstone with well rounded grains of quartz, fragments of silicified shells (some of which are pyritized), fragments of sideritic mudstones and intraclasts of micrite. Crinoid and echinoid spines, sponge spiculites, and coiled and bivalve shells have been identified within the shell debris. Void-filling megaquartz occurs within the cavities of fossil shells. Framboidal pyrite has also been found.

The origin of this unit is related to weathering of the underlying carbonates and development of a karstic soil. A similar karst-derived conglomerate of Early Pennsylvanian age in Kansas has been described by Nodine-Zeller (1981). Several features, such as the presence of extensive pyritization, black shale, and coal lenses indicate an absence of oxidation, a condition hard to visualize in a weathered zone. The presence of framboidal pyrite and bioturbation in the shales suggests a probable marine influence. A possible explanation for the formation of this unit could involve, therefore, the drowning of a karst-derived breccia deposit by an advancing sea. The consequences of this premise in the context of the regional paleogeography will be discussed later.

CUT BANK SANDSTONE

General

Glaister (1959) subdivided the basal sandy interval of the Mannville Group into two members: the Sunburst, and the underlying Cut Bank. Although in Montana, where these units have been named, the Sunburst/Cut Bank distinction can easily be made (Hopkins, 1985), such a distinction is not possible in the present area. As will be discussed later, the Cut Bank Sandstone does indeed display two contrasting lithofacies but, due to their complex interrelationship, they cannot be treated as two distinct formations. Therefore, a single formation name — Cut Bank Sandstone — will be applied to the strata lying between the Ostracode Zone and the Deville Formation.

This unit may comprise a single sandstone, or a multistoried one with shale interbeds. A blocky or fining-upward gamma-ray log pattern is typical, but locally it may also be coarsening-upward. The Cut Bank Sandstone is thickest between Ranges 18 and 17 W4 and Townships 1 and 11, where it forms the thick Taber Sandstone complex (Fig. 9) located in the Cut Bank Valley of Hayes (1986). Hayes believes that the Cut Bank does not extend beyond this valley to the east, but according to the present interpretation it is actually a continuous unit (Figs. 5, 19).

Petrography

The sandstone making up this unit varies from well sorted quartzarenite to poorly sorted lithic (chert) wacke. The

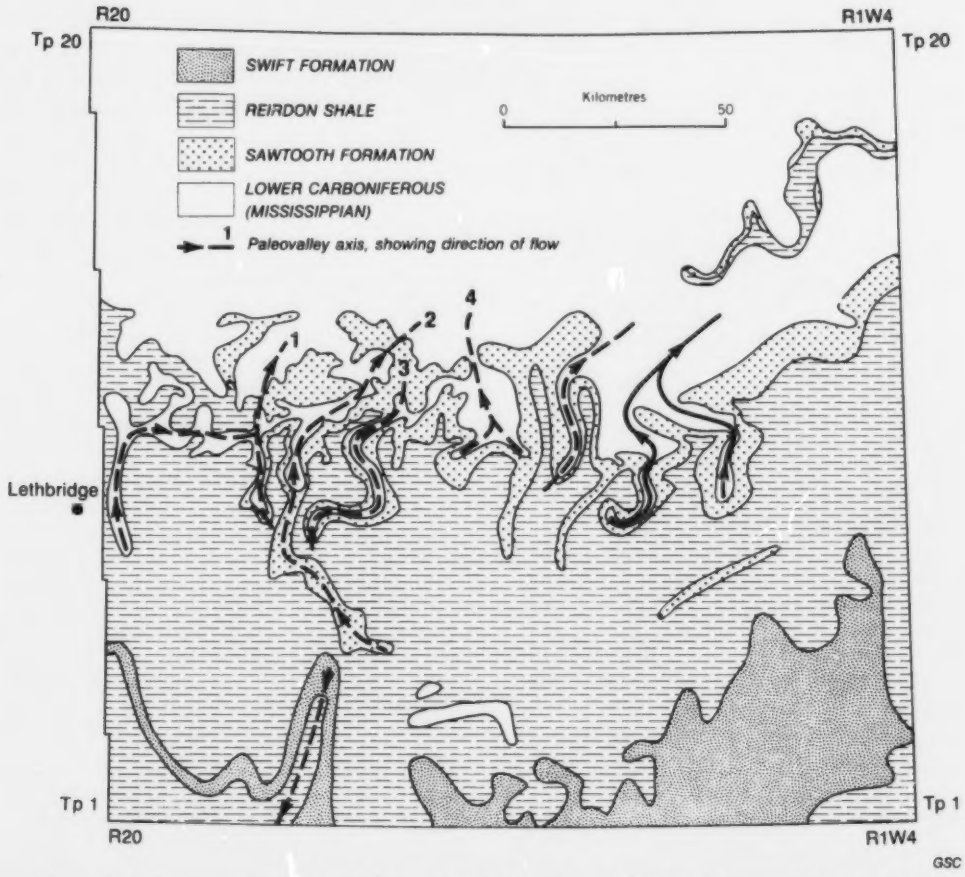


Figure 8. *Paleogeological map of the surface below the sub-Mannville unconformity. Well-density approximately 1.8 wells per township. Probable location of paleovalleys marked by numbers 1, 2, 3, etc.*

quartz/chert ratio varies from 3:1 to 1:2. The amount of cement varies from almost nil in tight sandstones with sutured grain contacts to 20 to 30 per cent in others. Quartz overgrowths seem to have developed first, followed by carbonate and kaolinite cements. Quartz grains constitute two populations: a medium grained (0.35-0.50 mm) well rounded one, and a fine grained (0.08-0.10 mm) angular one. At least three varieties of chert are present: 1. spherulitic, 2. microcrystalline mosaic, and 3. organic (sponge spiculite). Sideritic mudstone clasts and sphaerosiderite grains are common. Pyritization is ubiquitous.

OSTRACODE ZONE

General

This shaly zone, which occurs between two sandstones, the Cut Bank below and the Glauconitic above, contains limestone, black bioturbated mudstone and very fine grained sandstone. Coquina beds with shells of ostracodes, pelecypods and gastropods are common. The maximum thickness of the unit is 25 m. In places it shows a continuous progradational sequence into the Glauconitic Sandstone above. In log expression, it is reflected as a recessive, high gamma-ray zone between two low gamma-ray zones.

Petrography

In thin section, most limestones appear to be recrystallized biomicrite with abundant quartz grains that in places form distinct, fine grained sand layers. Disseminated pyrite is abundant and many shells are pyritized. Parallel lamination, marked by clay and burrow-fills, can be recognized. Shells are mostly entire. Intraclasts of shell-bearing limestone and clasts of sideritic mudstone may occur. The sandstone is a carbonate cemented, fine grained quartzarenite with shell debris and disseminated pyrite.

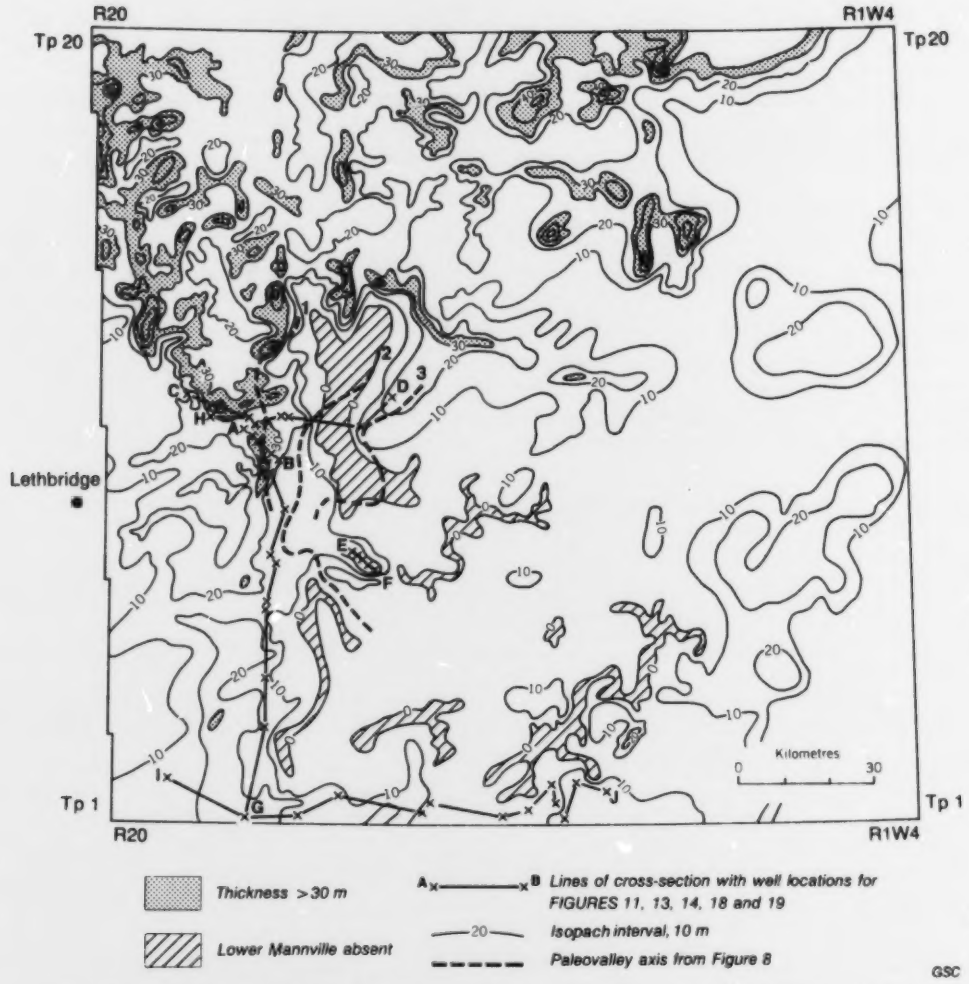


Figure 9. Isopach map of the "Lower Mannville interval" (Deville and Cut Bank) in the study area. Valley axes 1, 2 and 3 are derived from Figure 8. Note coincidence of axis 1 with the isopach thickness axis. Axes 2 and 3 do not show such correspondence. Well-density approximately 8 wells per township. (Modified from AGAT, 1981.) Location of cross-sections in Figures 11, 13, 14, 18 and 19 shown by lines AB, CD, EF, GH and IJ.

GLAUCONITIC SANDSTONE

The name "glauconitic" is a misnomer for this unit because, although this sandstone contains glauconite in central Alberta, this mineral is generally absent within the study area. Out of more than one hundred samples examined, only two or three grains of glauconite have been detected, and these occurred in only three samples.

Two facies of this sandstone are recognized. The first is a 10 to 30 m thick sandstone comprising the top of a coarsening-upward sequence (shoreline facies) that starts from the Ostracode Zone below. The second facies is also 10 to 30 m thick, has an erosional base that cuts through the Ostracode Zone, and displays a blocky or fining-upward gamma-ray log expression (channel facies). Petrographically, both sandstones are fine to medium grained, well sorted quartz- or chert-arenite with five to ten per cent feldspar (mostly microcline) and ubiquitous pyrite.

REGIONAL SETTING

Within the area of study, the Mannville Group occurs as a southwesterly thickening, predominantly shale-sandstone wedge that has been folded into a very shallow, northerly-

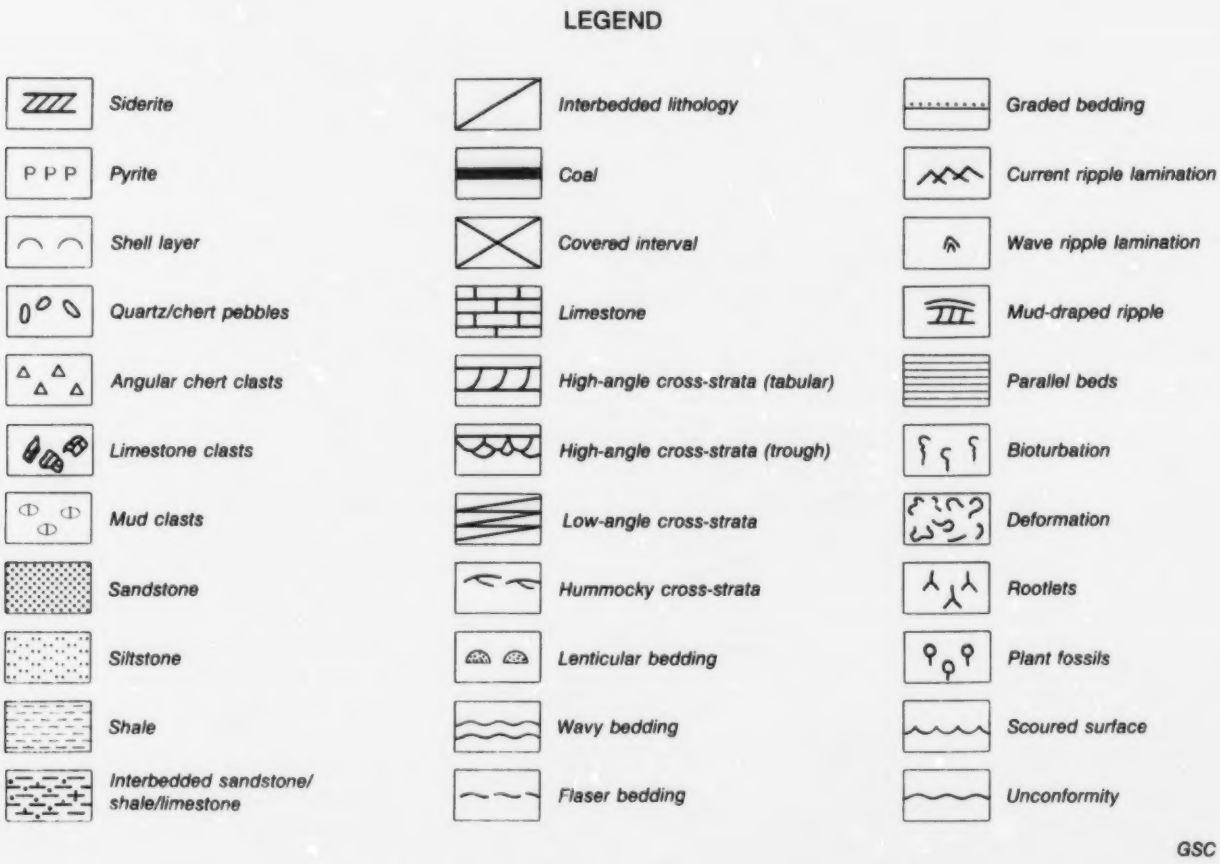


Figure 10. *Legend for all lithological columns and cross-sections (Figs. 4-7, 11, 13, 14, 18, 19, 21, 23, and 29).*

plunging anticline that constitutes the northern part of the Kevin-Sunburst dome (Herbally, 1974). This fold is responsible for very gentle northwesterly, northerly and northeasterly dips in the southwestern part of the area. Toward the north, the fold dies out and the Mannville strata show a persistent southwesterly dip toward the Alberta basin.

As described above, Mannville strata are underlain by Jurassic rocks belonging to the Ellis Group in the southern part of the area, and by Mississippian carbonates in the north, and are overlain by the Bow Island Formation, which consists of a series of coarsening-upward sandstone sequences encased in marine shale.

THE SUB-MANNVILLE UNCONFORMITY

The unconformity surface at the base of the Mannville Group, which cuts into Devonian and Mississippian carbonates in central Alberta and Jurassic shales and sandstones in the southern part of the province, has been mapped in detail by earlier workers. Undulations in structure contour maps of this surface have been analyzed by several authors using sophisticated statistical filtering devices to eliminate post-Mannville structure and bring out true paleotopographic features, although not always with great success (Ranger, 1983; Robinson et al., 1969; Sonneveld and Murray, 1982).

The earliest worker to comment on the land surface represented by the sub-Mannville unconformity was Beltz (1953), who considered the surface to be of "very low general relief". Subsequent workers in Alberta, Saskatchewan and Montana have reconstructed the paleodrainage pattern of the whole region on several different maps showing widely divergent interpretations (Bokman, 1963; Carrigy, 1967; Christopher, 1974, 1980; Martin and Jamin, 1963; Martin, 1966; Maycock, 1967; McGookey, 1972; McLean, 1977, 1983; Ranger, 1983; Ryer et al., 1983; Williams, 1963).

The basis for all these reconstructions was either the isopach map of the Mannville Group, or the structure contour map of the top of the Mississippian. The roles of differential compaction, subsidence and post-Mannville

structure were not generally considered in these interpretations. Only Martin (1966) recognized that isopachs of the Mannville strata are not a direct reflection of the paleotopography of the pre-Mannville erosional land surface and took precautions to account for differential compaction.

INCISED PALEOVALLEYS

Most previous workers have interpreted the basal sediments of the Mannville Group (Cut Bank Sandstone of this study) as aggradational valley-fill occupying incised paleovalleys on the sub-Mannville unconformity surface (Ryer et al., 1983). A large north-flowing river system with a complicated system of tributaries was reconstructed by McLean (1977, Fig. 7), McLean and Wall (1981, Fig. 5) and Jackson (1985, Fig. 19). Within the area of the present study, Hayes (1986) has recently identified two incised valleys in the unconformity surface which he named the Cut Bank and Whitlash valleys. Coarse, sandy sediments, interpreted as braided river deposits, fill these incised valleys forming an overall eastward-thinning wedge.

Most previous authors used the thinning of the underlying Jurassic rocks as evidence of post-Jurassic erosion, and suggested that it was this erosion that carved out the paleovalleys. However, this interpretation may not be correct, and as Andressen (1977) suggested, erosional patterns detected on a paleogeological map are more reliable indicators of paleodrainage patterns. With this in view, a paleogeological map of the sub-Mannville unconformity surface has been constructed for the area studied, to identify probable paleovalleys.

The paleogeological map (Fig. 8) has been prepared from a computer generated plot of approximately 728 well data-points from the datafile of the Energy Resources Conservation Board of Alberta. The well density is approximately 1.8 wells per township. Boundaries between formations have been hand drawn. The map shows the subcrop pattern of four pre-Mannville formations: undifferentiated Mississippian carbonates, and the Sawtooth, Rierdon, and Swift formations (belonging to the Jurassic Ellis Group).

In the northern part of the map, the Mississippian–Jurassic boundary, which is highly indented, displays a number of narrow re-entrants of Mississippian rocks within the extensive Rierdon subcrop area. As all the formations are subhorizontal, and dips rarely exceed 2° (measured from available dipmeter logs and two structure contour maps, one of the sub-Mannville unconformity surface and the other of the base of the Fish Scale Sandstone), it is assumed that the paleogeological map reflects V-shaped erosional valleys of horizontal beds, and a number of probable erosional valleys marked 1, 2 and 3 etc. have been sketched on the map. Assuming that the slope of the land surface was steeper than the dip of the beds, these valleys are an indication of north-flowing rivers. These tentative valley axes can, therefore, be superimposed on other maps to verify whether or not they correspond to expected facies patterns of valley-fill.

Valley axes 1, 2 and 3 fall within an area of thick sandstone called the "Taber complex" (Herbally, 1974), which accumulated during deposition of the Lower Mannville, and which is an important hydrocarbon reservoir in the area. The isopach map of the Lower Mannville strata in this complex (Fig. 9) shows one isopach "thick" axis closely following valley axis 1. Although axes 2 and 3 fall within the limits of the Taber complex, they do not follow isopach trends.

Valley axis 1 also is found in the axial region of the "Cut Bank Valley" mapped by Hayes (1986) and axes 2 and 3 are situated near its eastern margin. At the northern end of this valley, a depression or "low" in the Mississippian surface has been identified from seismic profiles by Taylor (1984) in a small area occupying four townships (see Figure 28a).

Therefore, Cut Bank Valley does represent an incised paleovalley filled with the sediments of the Lower Mannville, and possibly occupies a zone of greater subsidence. Other valley axes identified in Figure 8 do not seem to relate to isopach patterns. Streams flowing over these valleys must have been shallow and short, and their sedimentary cover must have undergone a complex history of differential subsidence and compaction to erase the effect of paleotopography.

Although most valleys suggest northerly-flowing streams, there is one example of a possible south-flowing one. A V-shaped subcrop pattern of the Swift Formation occurs in the southwestern corner of the area, and the Rierdon appears in the centre of the "V". This may be interpreted as a south-trending valley. An isopach "thick" of the Cut Bank Sandstone also lies close to it. Available dipmeter data also show southerly dips of cross-strata in this region. A southeasterly-flowing tributary of the main Cut Bank Valley river is a possible explanation of this feature. Figure 8 also suggests the presence of two possible paleogeographic features on the unconformity surface: a low-relief plain formed by the subcrop area of the soft Rierdon shale, and two highlands in the southeastern and southwestern ends formed by more resistant Swift Formation subcrops.

Nature of the valley-fill sediments

Sedimentary deposits filling the Cut Bank Valley belong to the Deville Formation and the Cut Bank Sandstone.

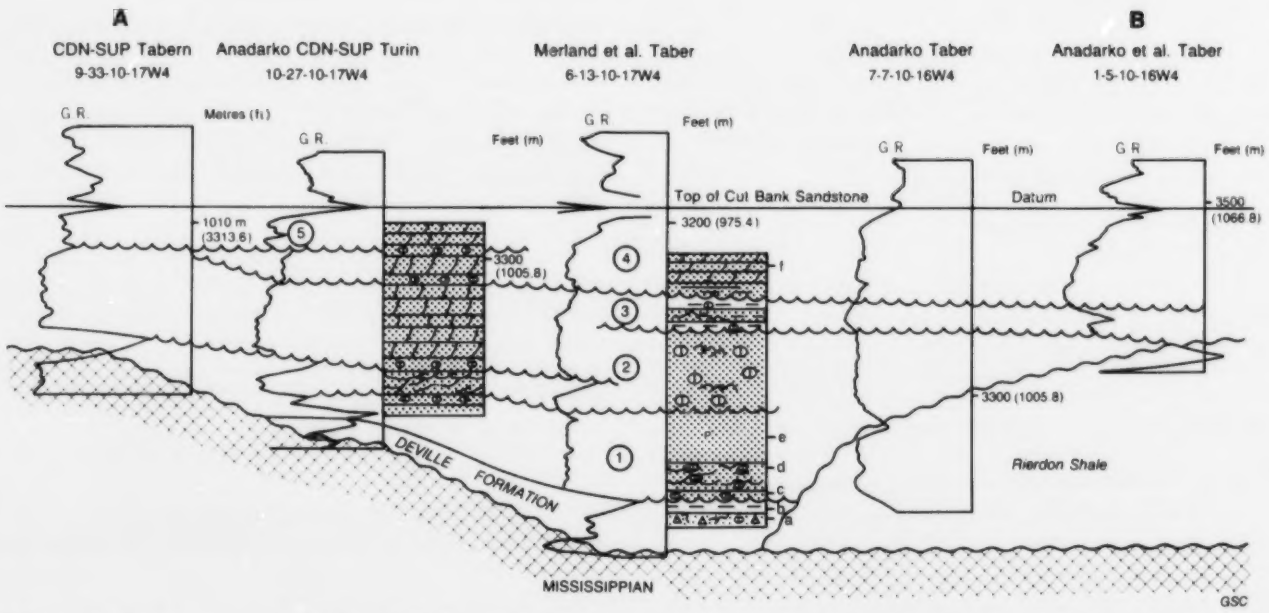


Figure 11. *Cross-section of the Cut Bank Formation oblique to valley axis 1, along line AB in Figure 9. Two cores in the middle reveal four scour-based fining-upward sequences, correlatable between wells. The deepest part of the paleovalley is occupied by the Deville Formation. 1-5, fining-upward sequences; a-f, locations of core segment photographs shown in Figure 12. For legend refer to Figure 10.*

Several cross-sections of wells that have been cored provide documentation of the nature of these sediments.

Two cores are available from the line of cross-section AB (Fig. 11), which crosses the channel obliquely (see Figure 9). Being oblique, the relief shown in this cross-section is less than the maximum. The most conspicuous feature of the valley-fill sediment in this section is the presence of four sandstone sequences (marked 1 to 4) seen both in the cores and in the gamma-ray log. Three of the sequences are scour-based with basal shale-pebble layers, and consist of crossbedded or crosslaminated sandstone with cosets ranging in thickness from 5 to 15 cm. The sequences, which range in thickness from 2 to 8 m, are correlatable between wells. The core from the Merland Taber well (6-13-10-17W4) consists more or less completely of these valley-fill sediments. Representative photographs of the core are shown in Figure 12. At the base of this core (Fig. 11) is a chert breccia with angular chert clasts set in a muddy to sandy matrix showing contorted laminae. The breccia is overlain by a grey to green structureless mudstone. These two basal units are lithologically completely different from the rest of the column and are assigned to the Deville Formation.

The origin of the scour-based sandstone sequences can be attributed to catastrophic floods or annual flood cycles, or repeated episodes of channelling and filling due to avulsions. The overall character of the channel sediments conforms to that of braided river deposits (Rust, 1980).

The same multicyclic sequence is also represented in another cross-section farther north across the same valley axis. In this cross-section however, a different facies (Facies 2 in Figure 13) appears near the top of the channel. This facies consists of very fine grained sandstone and siltstone with contorted laminae, bioturbation and ubiquitous pyrite. Although Facies 2 normally overlies Facies 1, they may also be interbedded, as shown in Figure 14. Detailed discussion of facies relationships of the Cut Bank Sandstone will be presented next.

FACIES OF THE CUT BANK SANDSTONE

Description of the facies

As mentioned earlier, the Cut Bank Sandstone displays two basic facies, each characterized by their geophysical (mostly gamma ray) log signatures, vertical grain-size trends, sedimentary and biogenic structures, and general lithology:

Facies 1. Cross-stratified, medium to coarse grained, gravelly sandstone (channel facies). This facies can further be subdivided into at least three subfacies:

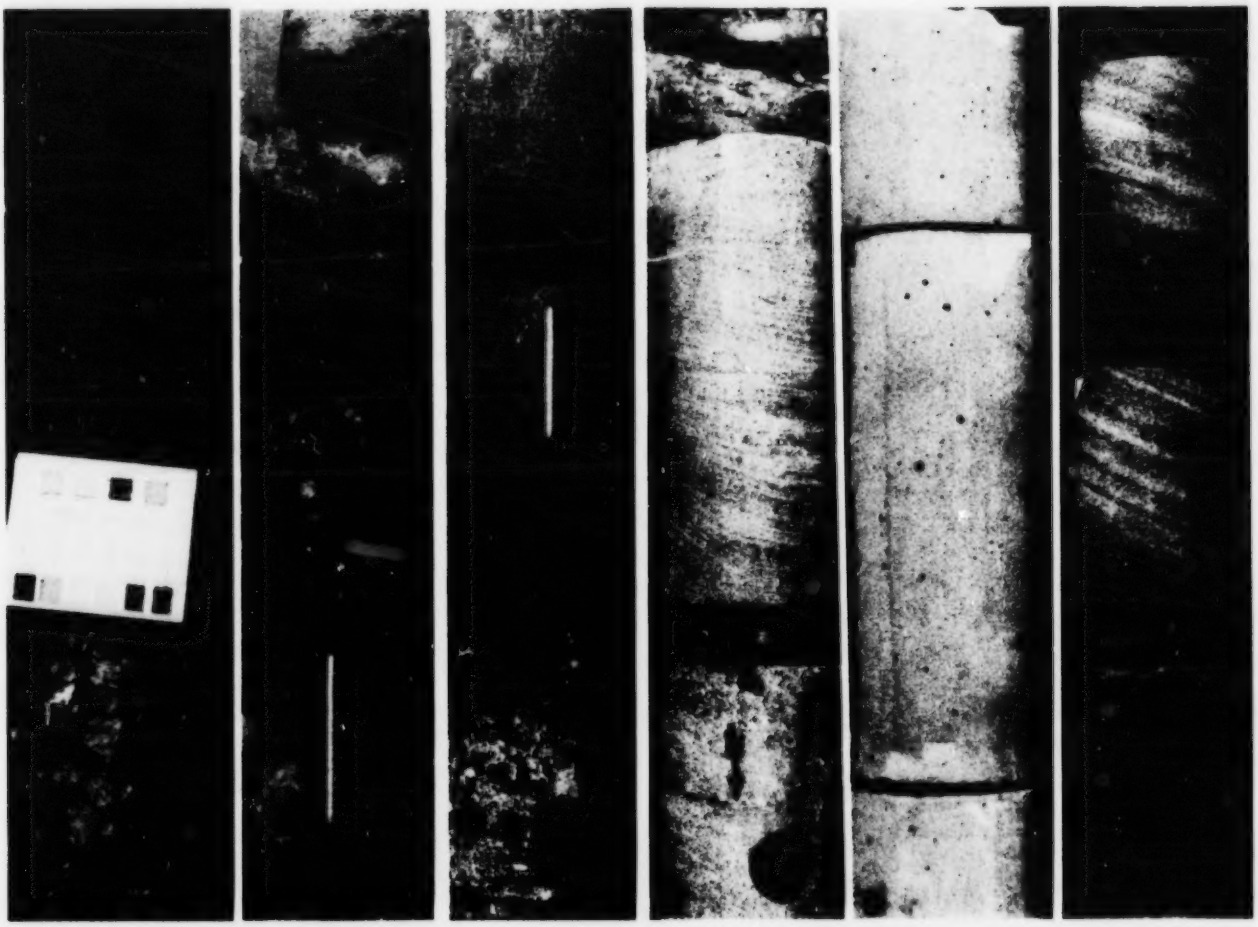


Figure 12. *Photographs of cored valley-fill sediments. Locations of core segments photographed are shown in Figure 11. Pen is 15 cm long and width of core is 10 cm.*

a. Deville Formation showing angular chert clasts in an argillaceous sandstone matrix.

b. Structureless chert-pebble conglomerate with rounded pebbles in a sandy matrix.

c. Graded pebble layer with crude parallel bedding at the base of a fining-upward sequence.

d. Scoured base of a gravelly, coarse grained sandstone with high-angle tabular (?) crossbeds.

e. Structureless, fine grained sandstone with pyrite nodules (black spots).

f. High-angle tabular crossbedded, medium grained sandstone. Crossbeds 10 to 15 cm thick.

1A: Multiple fining-upward units (1-2 m each) of scour-based, crossbedded, gravelly sandstone (see Figure 11).

1B: Single fining-upward units (10 m) showing a complete gradation from gravelly, coarse grained sandstone at the base to mudstone at the top (Figs. 16, 17).

1C: Single units with thick (≅10 m), homogeneous, low-angle crossbedded, fine grained sandstone overlain by very fine grained, crosslaminated sandstone (Figs. 14, 15a, b, c).

Facies 1A, which has been described in detail in connection with the channel sediments before, is the most common one. Both Facies 1A and 1C are devoid of mudstones, contain conglomerate layers and show overall the character of braided river deposits. Comparison with facies models of braided river sediments (Miall, 1977, 1980; Rust, 1980) indicates that Facies 1A, a dominantly sandy cyclic deposit, is comparable to the south Saskatchewan model. Facies 1C could be the record of an ephemeral stream comparable to the Bijou Creek model of Miall (1980). Facies 1B, a thinner, sandy

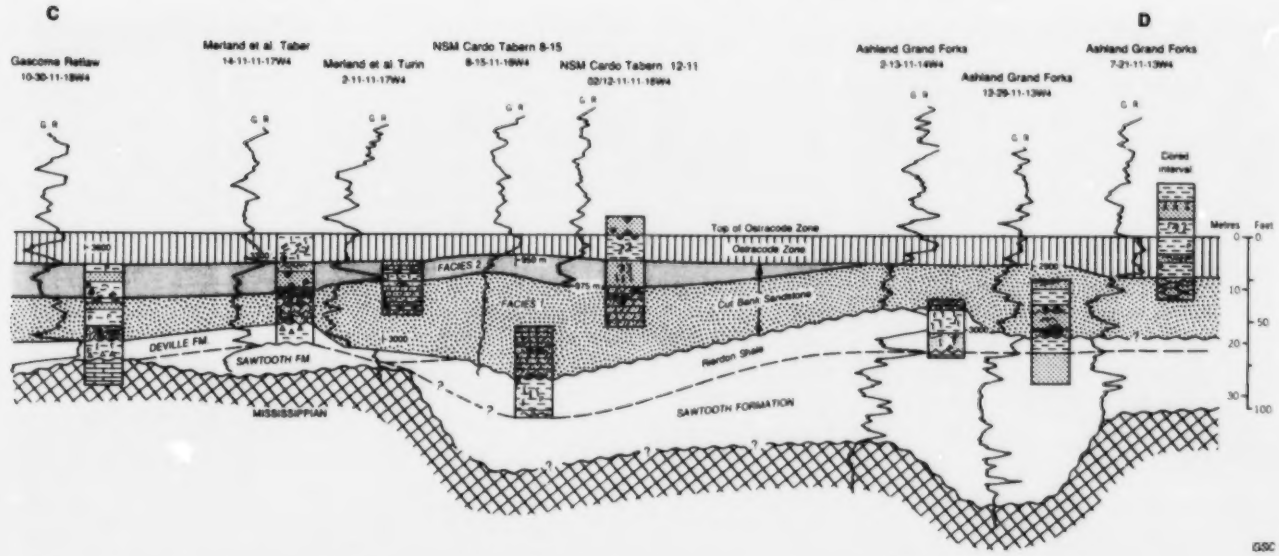


Figure 13. *Cross-section through valley axes 1 and 2 along line CD in Figure 9. Cores illustrate the lithology of the Mannville strata and older rock units. For description of Facies 1 and 2, see text. For legend, refer to Figure 10.*

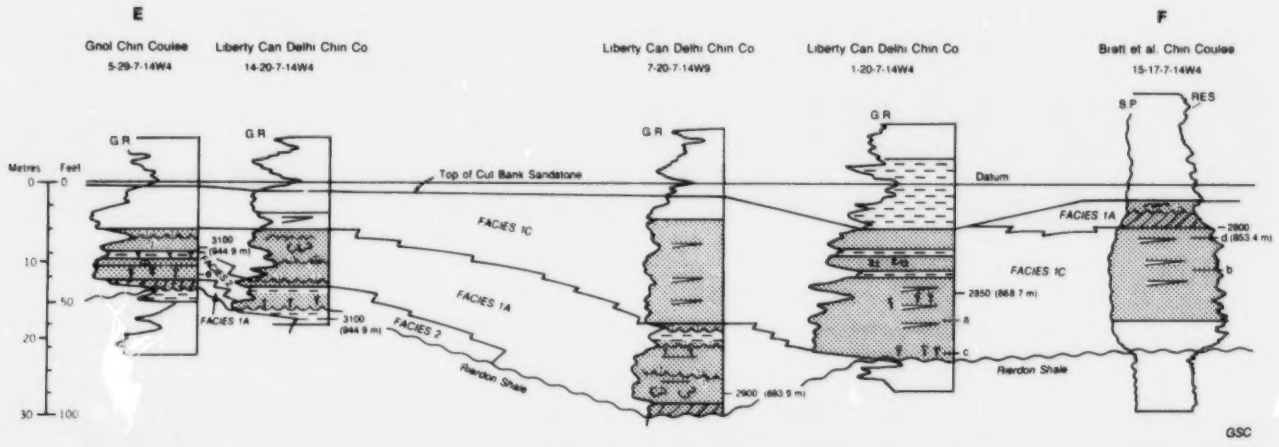


Figure 14. *Facies relationships between Facies 1A, 1C, and 2, illustrated by log expressions and core lithology of five closely spaced wells. Location of line EF is shown in Figure 9; a-e, locations of core segment photographs shown in Figure 15; G.R., gamma ray; S.P., spontaneous potential; RES, resistivity. For legend refer to Figure 10.*

cyclic unit, is a variant of 1A and may be accommodated within the south Saskatchewan model. Relationships between Facies 1A, B and C may be very complex, as illustrated in Figure 14.

Facies 2. Fine grained, homogeneous or contorted and bioturbated sandstone (bay-lagoon facies).

This facies is characterized by a blocky, indented gamma-ray log signature (Figs. 13, 14), a fine uniform grain size with almost no vertical trend, and a structureless or highly contorted or mottled appearance. Bioturbation in most cases is accompanied by an intense deformation of the sediments by liquefaction and water escape. Distinct burrow-fills are not common but have been recognized in a few cases (Fig. 15e). When all physical structures are not obliterated, crosslamination is visible. In rare cases, thin limestone beds with pelecypod shell debris have been found in this facies (see Figure 18B, north end). The presence of abundant bioturbation and rare shell debris and limestone in this facies

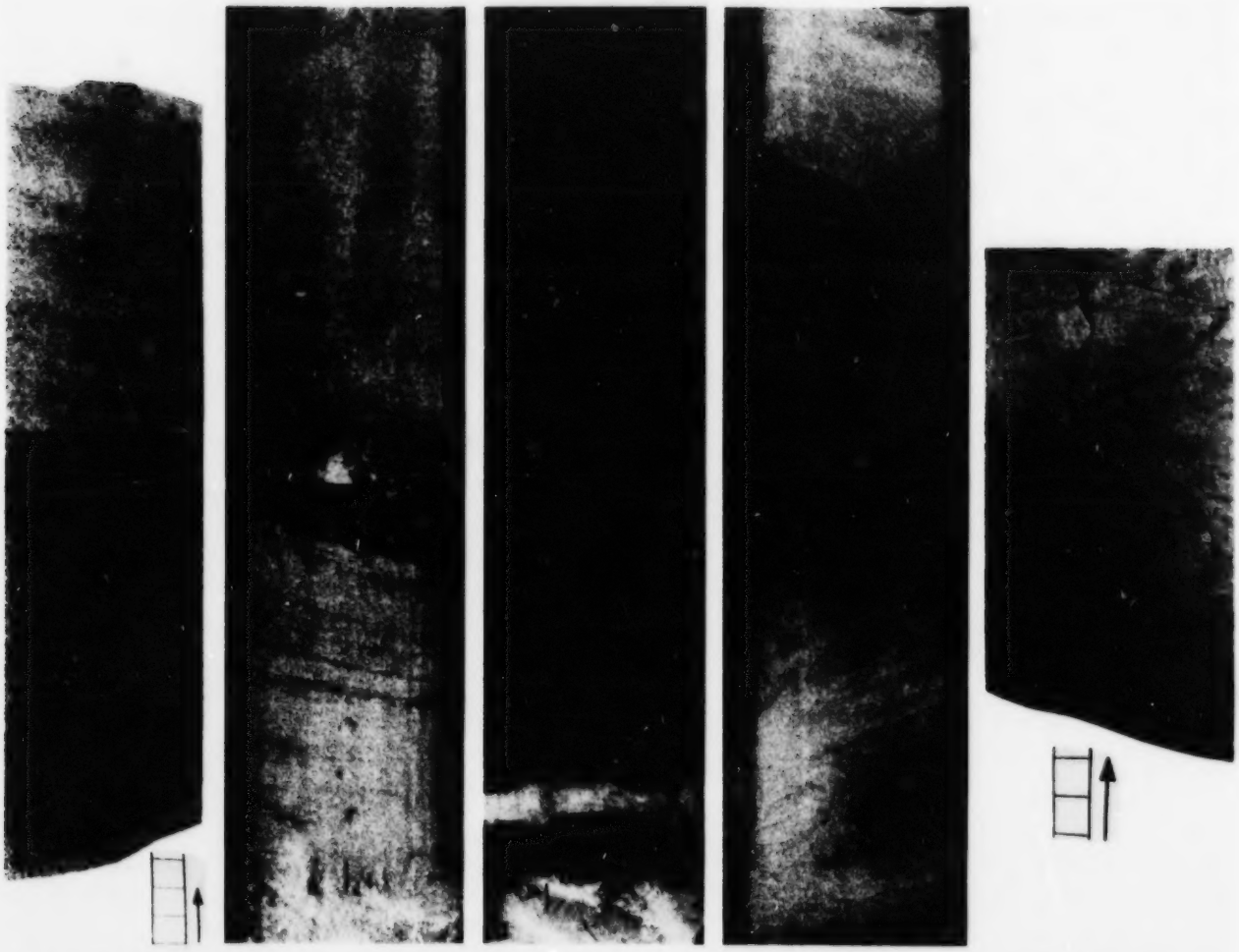


Figure 15. Photographs of core illustrating Facies 1C and 2. Locations of core segments photographed are shown in Figure 14. Scale in centimetres; tops in directions of arrows.

a. Medium grained sandstone showing faint, low-angle laminae. Facies 1C.

b. Low-angle laminae with mud layers, showing faint bioturbation.

c. Rierdon Shale – Cut Bank Sandstone contact. Tabular, crossbedded, medium grained sandstone (Facies 1A) overlies the unconformity, marked by diagonal pattern.

d. Contorted and bioturbated fine grained sandstone of Facies 2.

e. Distinct burrow-fills in Facies 2 sandstone. Circular cross-sections of ***Paleophycus burrows*** (P), *and an unidentified, subvertical, cylindrical burrow with spreiten (U).*

and a few occurrences of marine fossils (Fig. 27) indicate a marine influence, but the precise origin of these sediments cannot be determined from the available data. An estuary, an interdistributary bay or a lagoon are all possible depositional environments.

Facies 2 normally overlies but may also interfinger with Facies 1, and in rare instances (see 7-29-1-8W4 in Figure 19B) may underlie it, occurring directly over the unconformity surface. The spatial relationship between the two facies will be described in the next section.

Vertical relationships of the facies

The two cross-sections, one longitudinal and one transverse to the Cut Bank Valley (Lines GH and IJ in

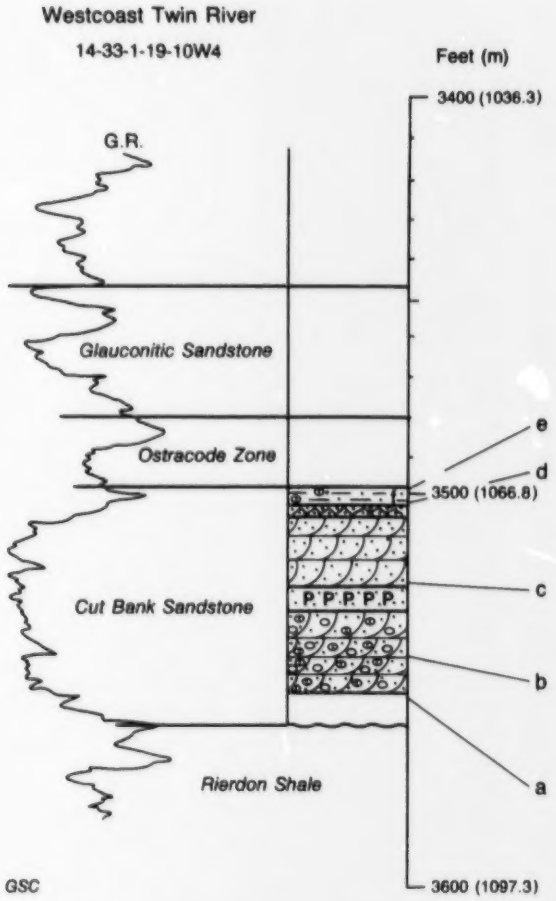


Figure 16. Gamma-ray log signature and core log of a typical example of Facies 1B, illustrating a single fining-upward unit. a-f, locations of core segment photographs shown in Figure 17. For legend refer to Figure 10.

Figure 9) illustrate the geometry and facies relationships of the Cut Bank Sandstone (Figs. 18, 19).

The section displayed in Figure 18 (A, B), drawn longitudinally along the valley, indicates a conspicuous variation in the thickness of the sandstone; two thick zones are separated by a thinner zone in the middle. Figure 18B, drawn on the basis of data from cores, shows the lateral and vertical relationships between Facies 1 and 2. Longitudinal facies relationships show the existence of a northern and a southern channel facies (Facies 1) separated by a middle zone consisting of the bay-lagoon sheet sand facies (Facies 2). It also shows that the lower part of the section is dominated by the channel facies and the upper part by an interfingering of both facies.

The transverse cross-section (Fig. 19A, B), at the southern extremity of the area studied, illustrates the geometry and facies relationships across the valley. The Cut Bank Sandstone has an overall sheet-like character, which thickens toward the Cut Bank Valley to the west. Lateral facies relationships show the almost exclusive presence of Facies 1 in the Cut Bank Valley, of Facies 2 in the middle, and an interfingering of Facies 1 and 2 at the eastern end. The most significant relationship is found in well 7-29-1-8W4 where Facies 2 directly overlies the unconformity and is overlain by Facies 1. Data from the four wells at the eastern end indicate a probable marine influence.

Areal distribution of the facies

A facies map of the Cut Bank Sandstone has been prepared from the records of 116 cored wells (Fig. 20). At each well, the facies have been identified with the help of the criteria discussed above. If the two facies are interbedded, the well has been classified according to the dominant one. The well density is not ideal and the actual facies relationships are, in fact, more complex than are shown on the map. However, they show some very broad overall patterns:

1. Facies 1 (Channel Facies) is confined to linear zones and also represents the thickest part of the stratigraphic unit.

2. The Cut Bank Valley is occupied mostly by Facies 1 sediments and is flanked on both sides by Facies 2 deposits. However, other linear zones of Facies 1 do not correspond to any identifiable valley on the unconformity surface.

3. The Cut Bank Sandstone is completely replaced by the Deville Formation (chert breccia) in a linear zone in the northeast corner of the map area.

General facies relationships

As discussed above, Facies 2 in most cases overlies Facies 1. If this relationship were universal, the two facies could be considered equivalent to two stratigraphic units, an underlying Cut Bank and an overlying Sunburst, as defined by Glaister (1959). A stratigraphic relationship such as this can be explained in terms of the burial of earlier fluvial channels by a transgressive sheet of brackish water sediments (bays, lagoons, estuaries etc.).

This model cannot explain the few examples where Facies 1 overlies Facies 2 (see Figure 18, eastern end). To explain this, either a later, second phase of channelling has to be assumed, or the two facies have to be considered contemporaneous and interdigitating. There is not enough evidence to decide between the two possibilities.

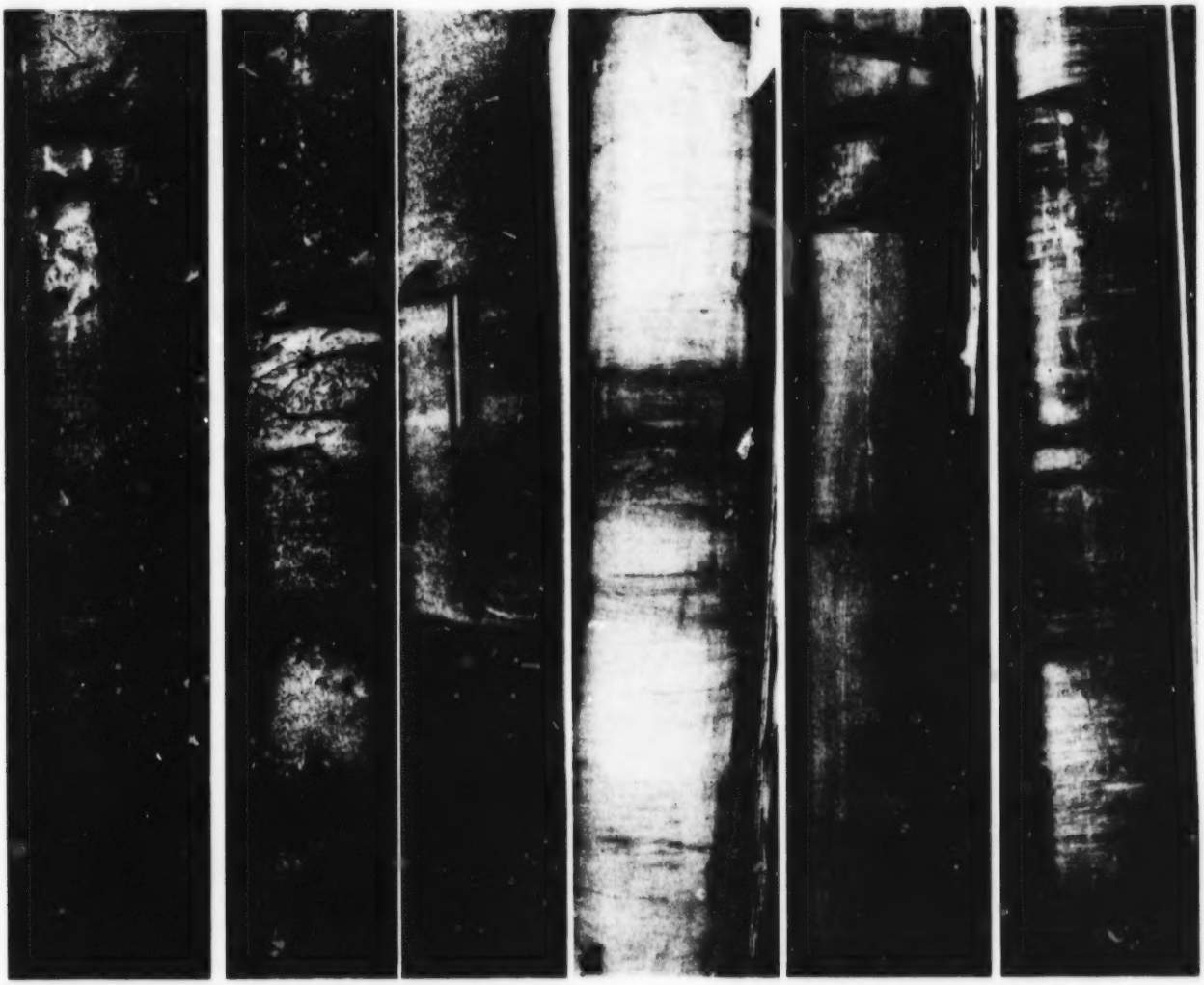


Figure 17. Photographs of core of Facies 1B, showing a complete record of a fluvial succession starting from channel lag gravel at the base to overbank mud at the top. Locations of core segments photographed are shown in Figure 16. Pen is 15 cm long.

a. Lag gravel – flat bedded sandstone overlain by graded gravel in scour pockets. More rounded clasts are chert; angular ones are mud clasts.

b. Lag gravel – parallel bedded sandstone with elongated mud clasts (near top), coal spars, and chert granules (near base).

c. Sandy point bar – tabular (?) crossbedded, well sorted, medium grained sandstone.

d. Natural levee – crosslaminated fine sandstone.

e. Overbank sand – fine sandstone with very thin ripple lamination.

f. Overbank mud – parallel and crosslaminated sandstone and mud.

FACIES OF THE OSTRACODE ZONE

The Ostracode Zone is recognized throughout the area as a shaly formation with a thin, more or less continuous limestone or marlstone bed at the top. Its thickness varies from 3 to 20 m, and averages 10 m. Three lithofacies occur in this zone, but their spatial relationships are too complicated to be represented on a map. Therefore, the relationships will be illustrated (Fig. 21) using the vertical

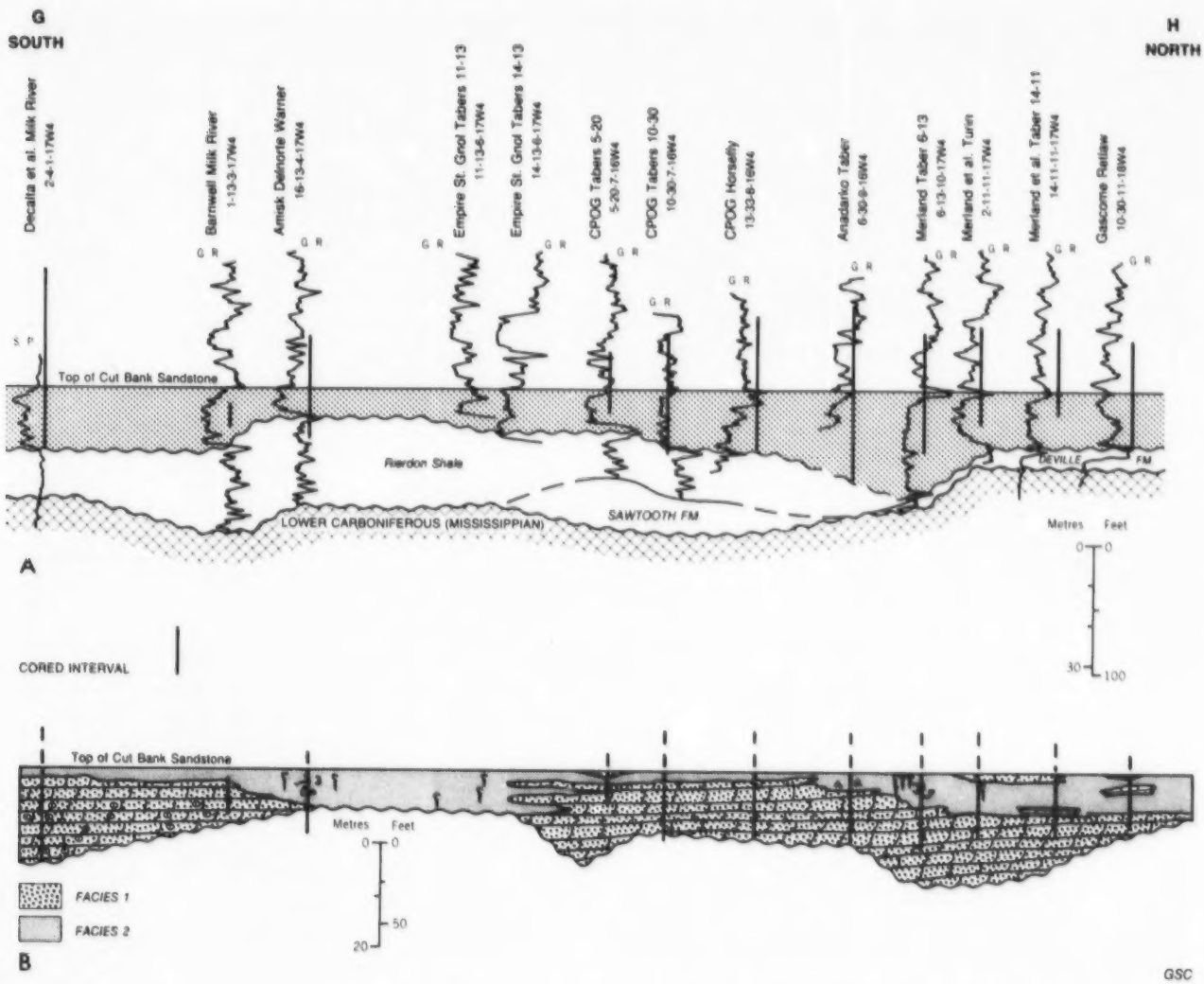


Figure 18. *Longitudinal sections of the Cut Bank Sandstone along line GH (see Figure 9) close to valley axis 1. For legend refer to Figure 10.*

A. Longitudinal channel geometry, showing two thick zones separated by a thinner zone.

B. Facies relationships along the channel. Facies 1 occurs in the lower part of the channel whereas Facies 2 either simply overlies it or interfingers with it near the upper part. The Channel Facies is absent in the middle where a divide was probably located.

sequences exhibited by three key wells, in one of which (Fig. 21A) a complete core record of the member is available. The three lithofacies are:

1. Bioturbated black mudstone
2. Lenticular or graded-bedded, very fine grained sandstone
3. Bioturbated dark limestone

Bioturbated black mudstone

This is the most common lithofacies of this unit. Lenses or thin layers of white siltstone are present, and the degree of bioturbation varies from almost none to one hundred per cent, in which case the rock is burrow-mottled and exhibits no detectable primary structure. Identifiable trace fossils include: *Chondrites, Paleophycus, Planc lites* and *Teichichnus.* Syneresis cracks are present and contorted laminae are common. In a vertical sequence, this facies

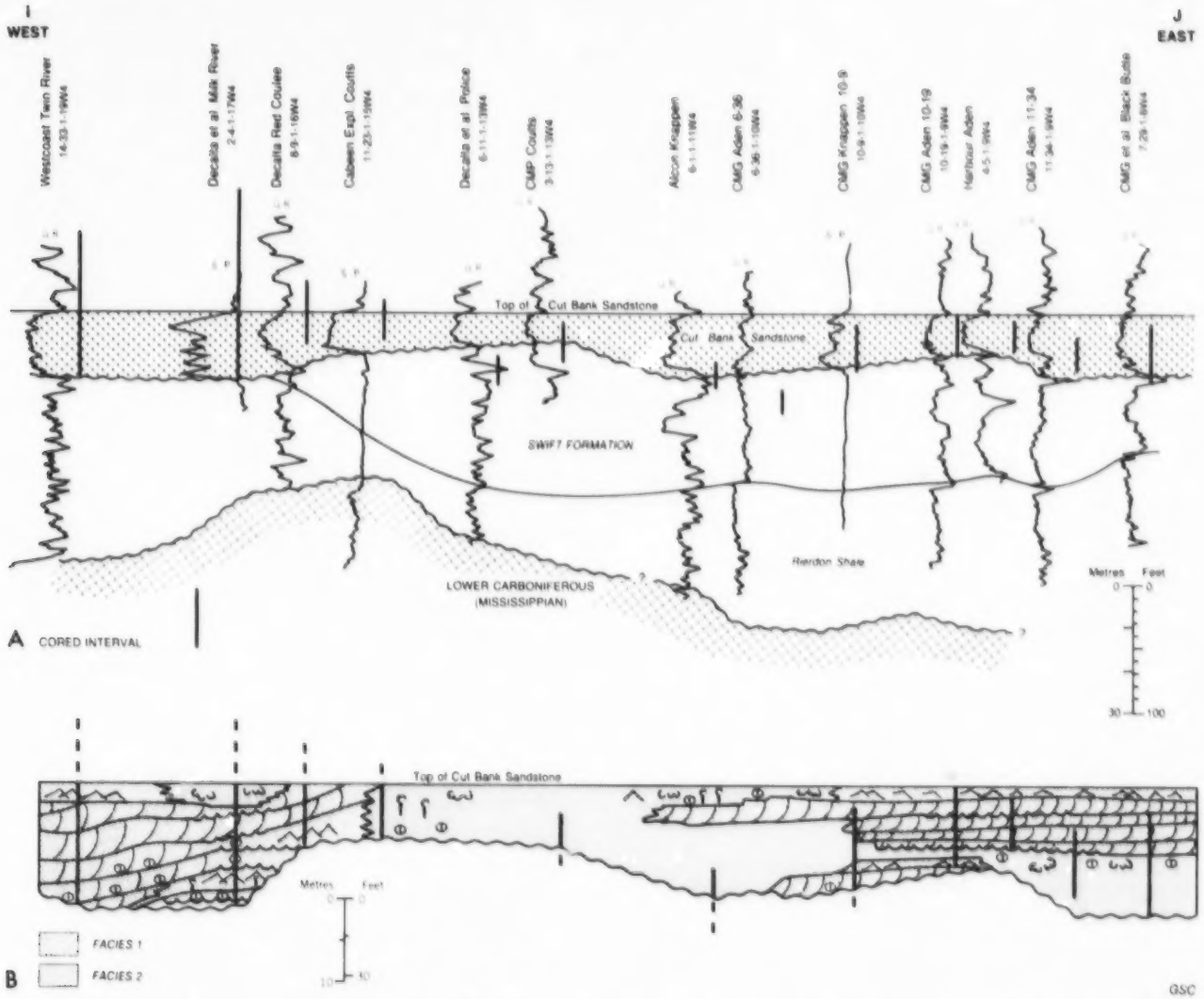


Figure 19. *Facies relationships in the Cut Bank Sandstone in the southern part of the area. Location of line IJ is shown in Figure 9. For legend refer to Figure 10. G.R., gamma ray; S.P., spontaneous potential.*

A. Log correlation and thickness variation in the Cut Bank Sandstone and the Jurassic formations below.

B. Facies relationships in the Cut Bank Sandstone. Note Facies 2 lying directly above the unconformity at the eastern end of the section. Interbedding of Facies 1 and 2 indicates a marine influence.

normally underlies the other two and in some instances it grades downward into a pure black shale exhibiting no bioturbation but containing lenses of coaly matter.

Thin bedded, very fine grained sandstone

In most vertical facies sequences, this facies overlies the black mudstone facies (see bottom part of Figure 21A). Physical sedimentary structures dominate over the biogenic ones and only a few trace fossils are present. Three types of bedding structures are present: 1. wave ripple lamination (Fig. 22d) — 2 to 3 cm thick, symmetrical, scour-and-drape structures; 2. lenticular beds (Fig. 22c, d) — starved wave ripples of fine sand encased in mud; and 3. graded beds (Fig. 22a, b) — 5 to 6 cm thick, normally graded sedimentary units.

Bioturbated limestone

Thin beds of argillaceous micritic limestone occur at random within this unit. They commonly contain scattered shells of ostracodes, pelecypods and gastropods. Normally

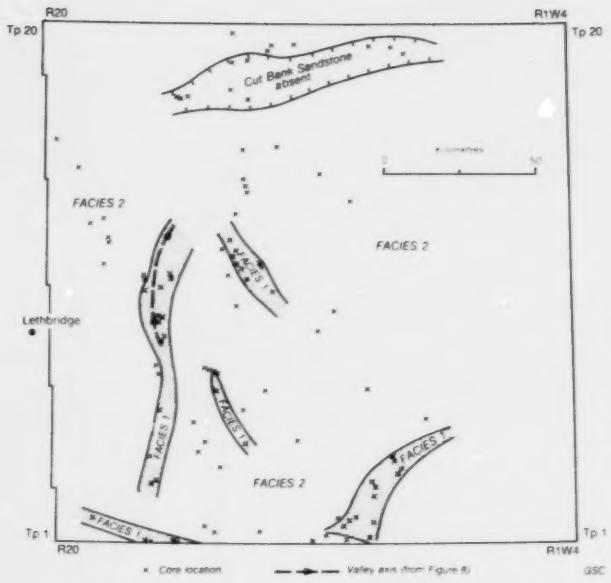


Figure 20. *Facies map of the Cut Bank Sandstone based on the lithology of 116 cored intervals. The map is based on 58 cores (see Appendix 1) from this study and 58 core logs from the AGAT report (1981). Note concentration of Channel Facies in linear zones corresponding to valley axis 1 (marked 1), identified from the paleogeological map in Figure 8. Facies 2 seems to be more extensive and sheet-like although the interpretation is limited by large areas with poor control. The Cut Bank is absent in the area shown and a thick chert breccia facies of the Deville Formation replaces it.*

they display wavy lamination, bioturbation and liquefaction structures. Vertical distribution may be random and several limestone beds may occur in a sequence, but a thicker (>1 m) limestone (Fig. 22e) is consistently present at the top of the sequence and is a traceable marker.

Facies sequence

The vertical sequence pattern of the three facies is quite complex and there are not many cores available in which the whole thickness of the Ostracode Zone is represented. However, the following generalizations may be made:

1. Two to four fining-upward units, each 1 to 3 m thick, make up the lower half of the zone and one coarsening-upward unit, 1 to 2 m thick, the upper half.

2. The fining-upward units comprise an upper part of bioturbated mudstone and a lower part, which consists of one of these three rock types:

   a) Wave-ripple laminated, fine grained sandstone units, each 2 to 5 cm thick

   b) Graded beds, 5 to 6 cm thick, showing normal grading from medium grained sand to silt

   c) Shell debris of pelecypods, gastropods and ostracodes

The sandstone units described in 2a, b and c above are the result of rapid, episodic sedimentation, and the bioturbated mudstones above them represent slow, low-energy, quiet water sedimentation.

A marine origin for the sediments of the Ostracode Zone in the area has been deduced from ubiquitous bioturbation, diagnostic trace fossils belonging to the *Cruziana* ichnofacies, and the presence of marine fossils. The style of sedimentation in the Ostracode Zone can be interpreted in terms of the fining-upward units, the coarsening-upward units, and the limestones.

1. Fining-upward units. These and a few examples of hummocky cross-strata, which are described below, may represent storm sedimentation units (Aigner, 1985).

2. Dense, micritic limestone layers. These deposits indicate a low clastic input and long contact of the water column with the sediment interface, indicating deepening of water. These have been interpreted as hiatal surfaces (Frazier, 1974) formed during peaks of transgression.

3. Coarsening-upward units. Units in which the number of sandstone beds in the column increases and the unit finally grades into the Glauconitic Sandstone above represent a progradational shoreline sequence (see Figure 23).

The Ostracode Zone records an extensive transgression that covered all of Alberta and must have extended into Montana (Burden, 1983; Jackson, 1985; Smith et al., 1985). Pocock (1980) considered it to be part of a middle Albian, continent-wide transgression, characterized by the dinoflagellate assemblage *Muderongia-Canningia*. Wanklyn (1984) considered it to be a fourth-order cycle within Vail's (1977) T5/R5 third-order cycle of global transgressions. A more detailed discussion of the documentation of this transgression in the area studied follows.

DEPOSITION OF THE OSTRACODE ZONE

Evidence for shallow shelf sedimentation

Although it has been generally accepted by most workers (except Farshori (1983), who did not recognize any marine characteristics in the unit) that the Ostracode Zone records

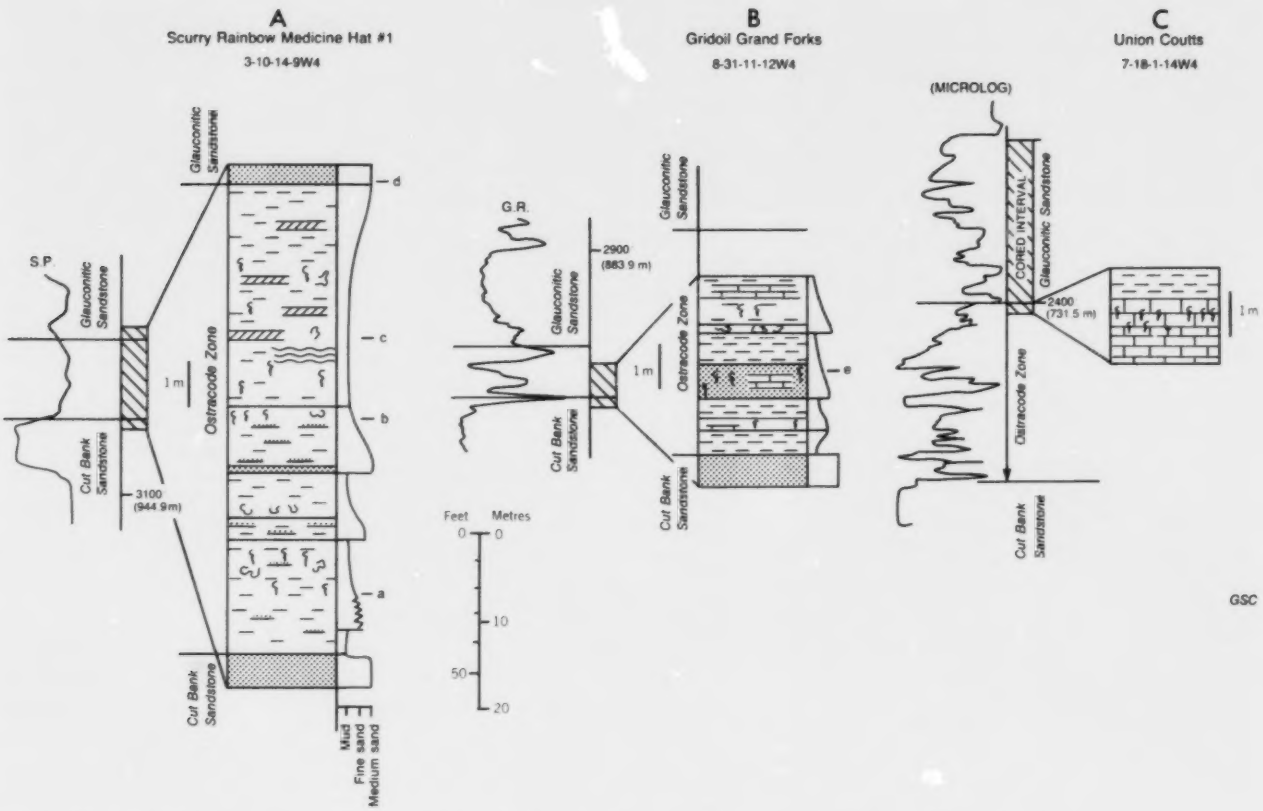


Figure 21. *Core lithology and log signature of the Ostracode Zone in three key wells. a-e, locations of core segment photographs shown in Figure 22. For legend refer to Figure 10. G.R., gamma ray; S.P., spontaneous potential.*

A. Three fining-upward sequences, each with graded beds of fine grained sandstone overlain by bioturbated mudstone. The topmost coarsening-upward sequence shows lenticular and wavy bedded, bioturbated siltstone with sideritic bands.

B. Three fining-up sequences with marlstone layers.

C. Only the topmost units, a bioturbated dark limestone, and a black shale, are recorded.

a marine transgression in southern Alberta, the prevalent view on the paleoenvironment of this unit is that it was marginal marine rather than open marine. According to Wanklyn (1985) it was restricted marine, according to McLean and Wall (1981) and Finger (1983) it was lagoonal and estuarine, and according to James (1985), the environment was a "calcareous sea". An offshore shallow shelf environment has been ruled out by earlier workers, mainly because the fossils derived from the Ostracode Zone in many cases represent a 'mixed' fauna (Finger, 1983) consisting of a purely marine component (foraminifers and dinoflagellates) and a fresh to brackish water component (ostracodes and charophytes).

Paleontological and sedimentological evidence from three key wells located in Townships 1 and 20 are presented in this section to establish that a shallow shelf environment existed in at least these three locations during the deposition of the Ostracode Zone sediments.

In two wells (Murphy Red Coulee 3A-5-1-16W4 and Empire State et al. Jenner 12-32-20-8W4) a typical progradational sequence, which records the offshore-shoreface-foreshore-backshore transition, has been found in the Ostracode Zone-Glauconitic Sandstone stratigraphic interval (Ryer, 1977).

In one well (K.S. Sinclair 10-29-20-13W4) the presence of a diverse foraminiferal assemblage consisting of nine species, together with echinoid spines and fish teeth, clearly indicates an open marine environment. This is the first recorded instance of an open marine fauna from the Ostracode Zone in southern Alberta (J.H. Wall, pers. comm.). In the other two wells, foraminifers and dinoflagellates found in the strata

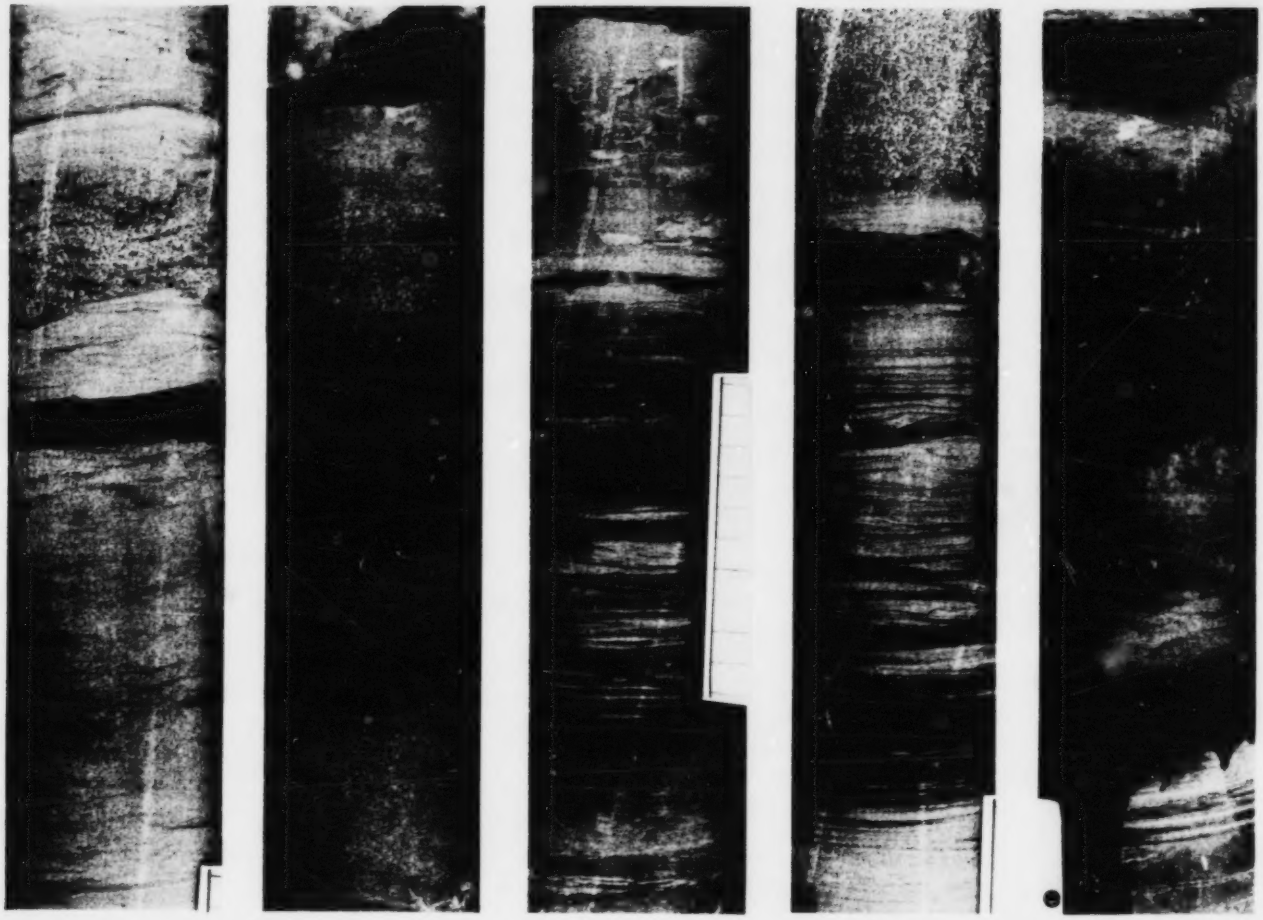


Figure 22. *Photographs of core showing various kinds of sedimentary units in the Ostracode Zone. Locations of core segments photographed are given in Figure 22. Scale in centimetres.*

a. A graded bed with ripple-laminated, bioturbated and convoluted top (top half), overlying ripple-laminated sandstone (bottom half).

b. Three graded beds with bioturbated (?) mudstones at top.

c. Lenticular bedded siltstone (middle) overlain by a graded bed, passing into contorted and bioturbated mudstone at the top.

d. Lenticular bedded siltstone showing wave-ripple lamination (WRL), the trace fossil ***Chondrites*** *(Ch), and a sharp contact with the overlying Glauconitic Sandstone.*

e. Laminated (bottom) and bioturbated (top) limestone.

corroborate an open marine environment. Fresh to brackish water ostracodes, associated in one well with dinoflagellates and foraminifers, can be demonstrated to have been transported into the sedimentary environment from areas of shallower water.

The following are descriptions of the sedimentary successions in these wells:

K.S. Sinclair 10-29-20-13W4

A diverse foraminiferal assemblage (see Appendix 2) consisting of nine species, of which *Haplophragmoides* spp. is the dominant one, was obtained from one sample of black, structureless mudstone from the Ostracode Zone in this well. The geophysical log, a lithological column constructed by Canadian Stratigraphic Services, and the core log showing

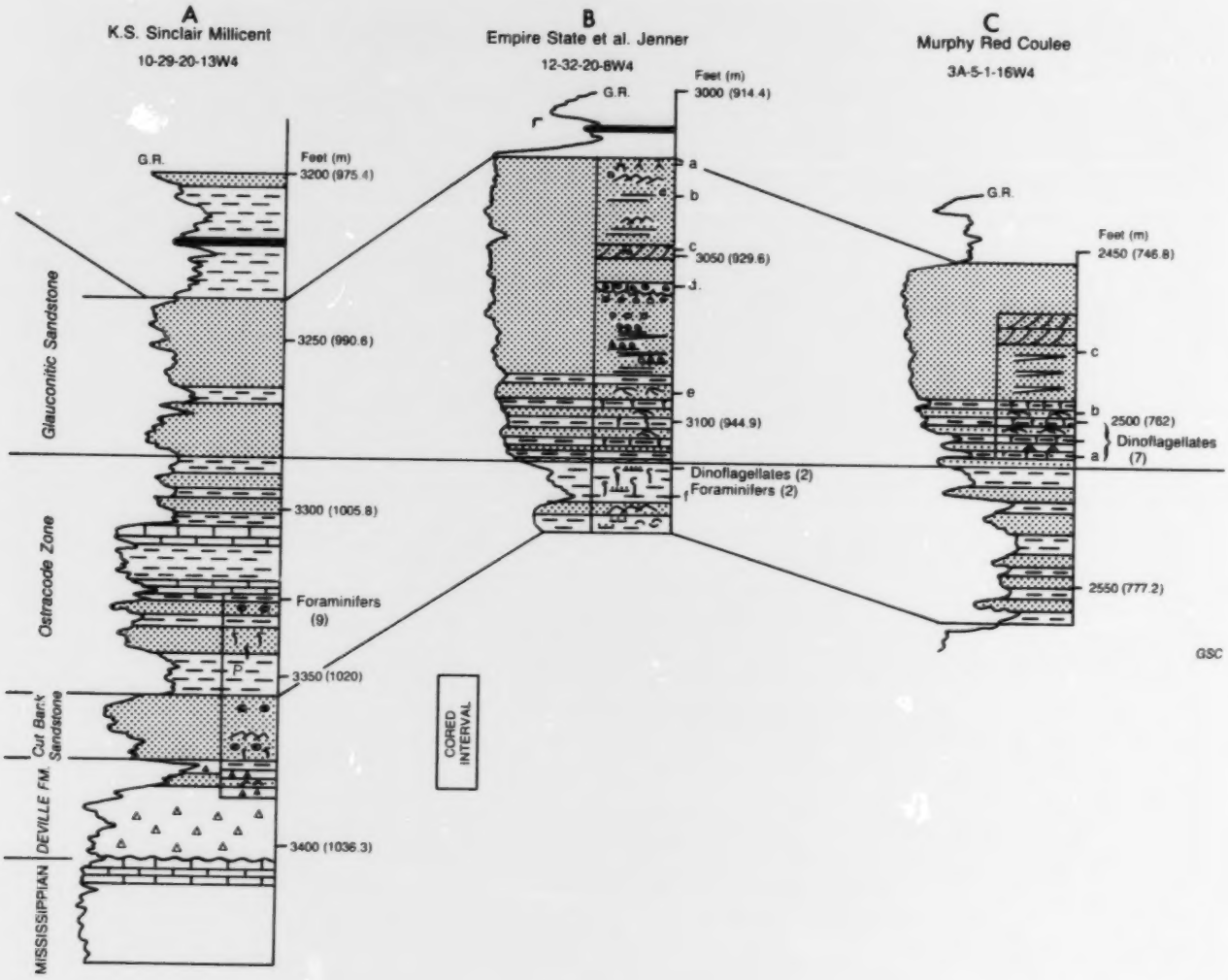


Figure 23. *Sedimentology and paleontology of the Ostracode – Glauconitic interval. (2), number of species observed in sample. For legend refer to Figure 10.*

A. Gamma-ray log for the K.S. Sinclair well. Lithologies (from lithological column constructed by Canadian Stratigraphic Services), detailed core log, and location of sample with foraminiferal assemblage.

B. Gamma-ray log and core lithology of the Empire State et al. Jenner well. Note typical progradational sequence and marine fossils. a-f, locations of core segment photographs shown in Figure 24.

C. Gamma-ray log with inferred lithology, detailed core log with sedimentary structures, and location of two samples with marine fossils in the Murphy Red Coulee well. A typical progradational sequence is illustrated in the log. a-c, locations of core segment photographs shown in Figure 25.

the location of the sample appear in Figure 23A. The sample also yielded abundant algal matter, which is indicative of a marine environment.

The lower 9 m of the Ostracode Zone in this well (Fig. 23A) represent a crudely defined coarsening-upward sequence overlain by an interbedded limestone-sandstone sequence. The sample analyzed came from the top part of this coarsening-upward sequence and may not indicate the greatest water depth, which is probably represented by the dark grey, slightly bioturbated, pyritiferous mudstones in the lower part of the sequence.

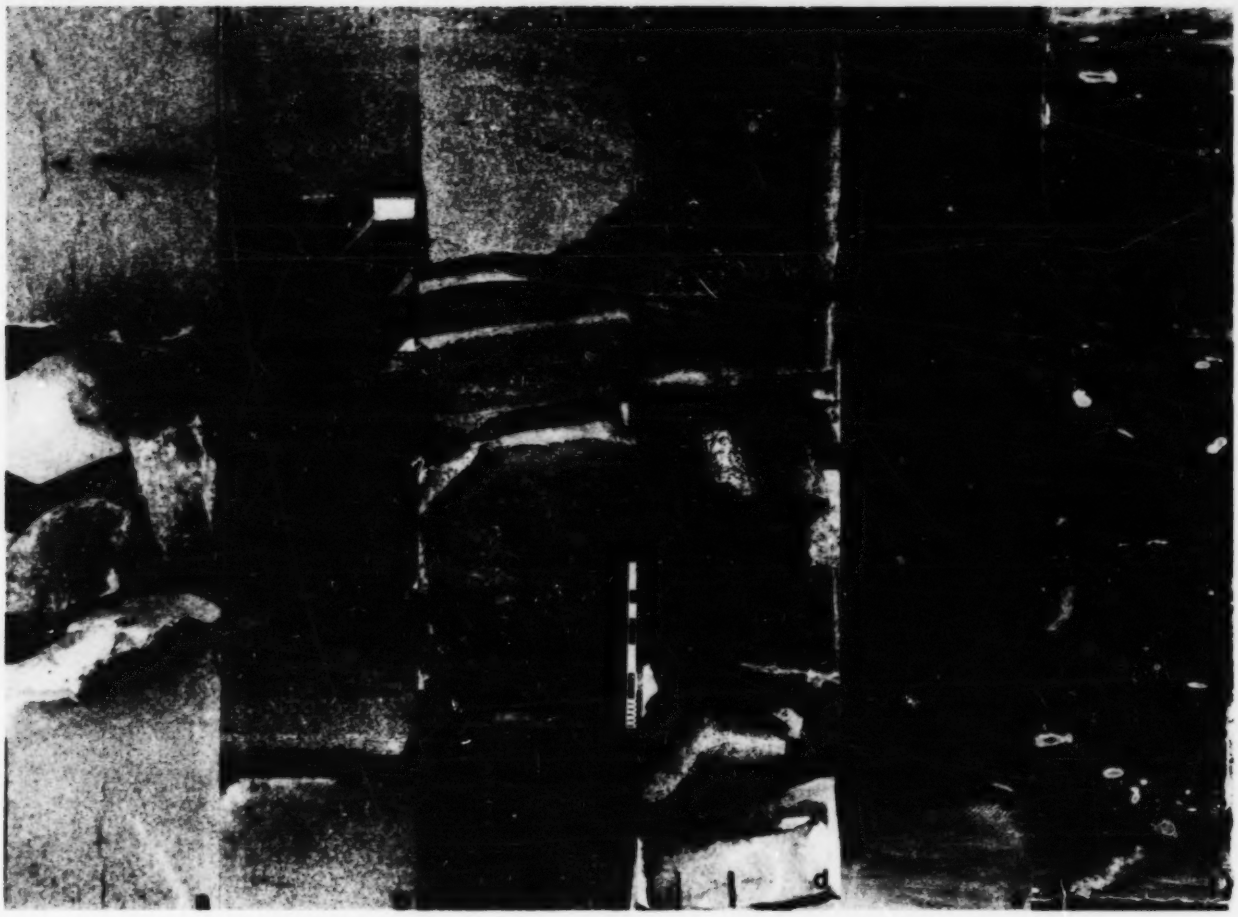


Figure 24. *Photographs of core from the Empire Jenner well showing a progradational sequence. Locations shown in Figure 23B. Gd, graded beds; Py, pyritized burrow.*

a. Ripple laminated and "rooted", fine grained sandstone at the top (backshore).

b. Parallel laminated or low-angle crossbedded, fine grained sandstone (foreshore).

c. Crossbedded, gravelly sandstone (upper shoreface).

d. Low-angle crossbedded sandstone and conglomerate. Note graded gravels with scoured base (near the top) indicating "storm" events (middle shoreface).

e. Bundles of low-angle converging laminae with low-angle truncation planes — probably hummocky cross-strata, indicating a storm generated sequence (lower shoreface).

f. Laminated mudstone with silt layers and pyritized burrows (offshore).

The progradational coarsening-upward sequence of the Glauconitic Sandstone occurs above the coarsening-upward sequence of the Ostracode Zone, probably indicating two(?) transgressive events in quick succession.

Empire State et al. Jenner 12-32-20-8W4

The same stratigraphic interval in this well shows a typical (Ryer, 1977) progradational facies sequence (Figs. 23B, 24) starting with a bioturbated mudstone (offshore) (Fig. 24f) in the Ostracode Zone, and ending in a rooted, crosslaminated sandstone (backshore) overlain by coal (Fig. 24a) in the Glauconitic Sandstone. Storm deposits exhibiting graded gravel layers (upper shoreface) and hummocky, cross-stratified (Fig. 24d, e), fine grained sandstones (lower shoreface) occur in the lower part of the Glauconitic Sandstone. Only 2.6 m out of the 15 m of the

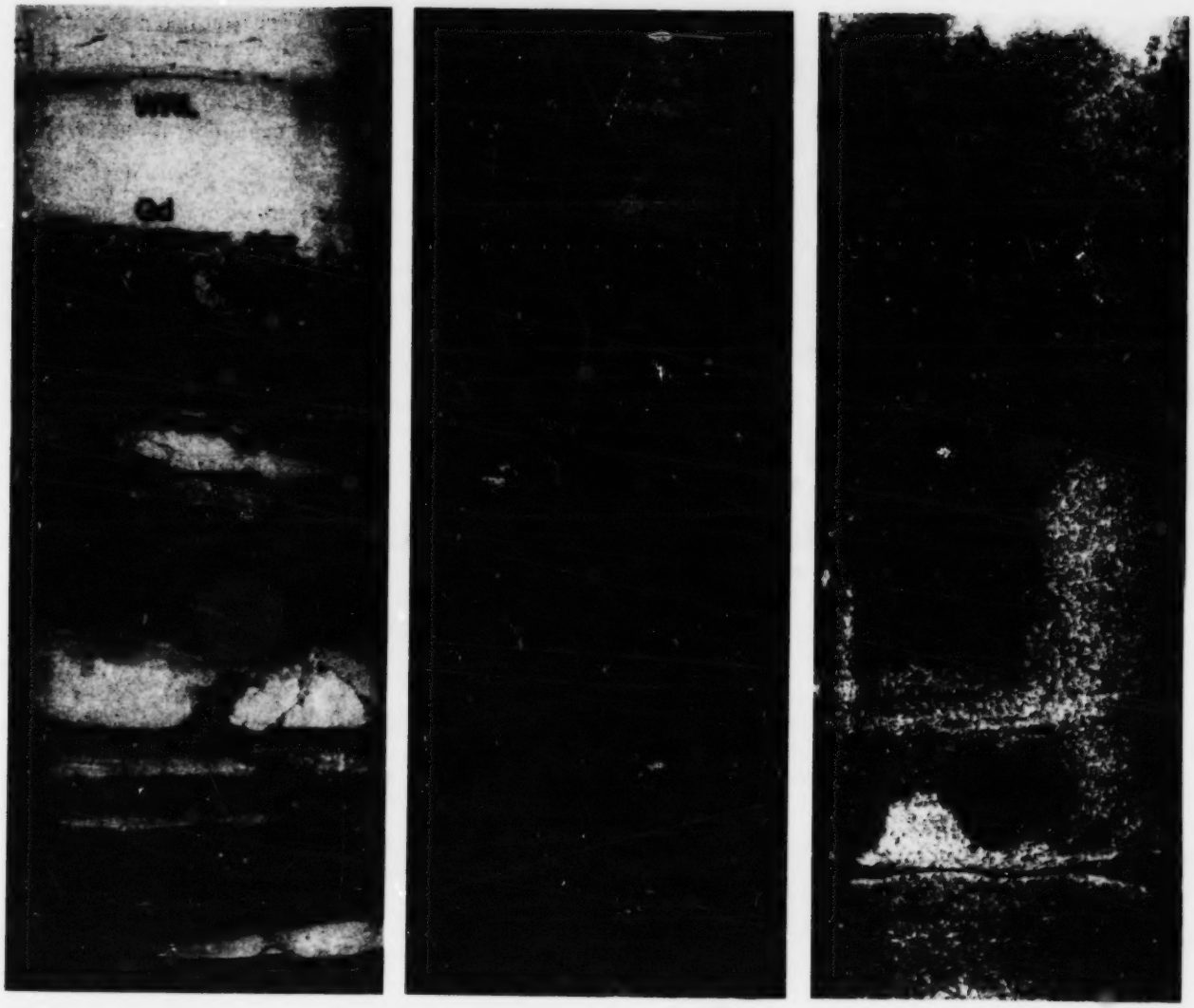


Figure 25. *Photographs of core showing the progradational sequence in the Red Coulee well. Locations shown in Figure 23C. WRL, wave-ripple laminae; Gd, graded bed; Sy, syneresis crack; EB, escape burrow.*

a. Bioturbated mudstone and lenticular, very fine grained sandstone with syneresis cracks (offshore), overlain by graded beds that are storm sedimentation units (offshore-shoreface transition).

b. Hummocky cross-stratification (HCS) in the lower shoreface.

c. Low-angle, coarse grained sandstone near the top of the sequence (foreshore).

Ostracode Zone were cored, but the succession overlying it clearly defines the paleoenvironmental location of the Ostracode Zone. Within the cored interval, the Ostracode Zone displays: 1. an upper, intensely bioturbated black mudstone, and 2. a lower black mudstone with 2 to 5 cm thick, graded beds of fine sand and unidentifiable shell hash. These graded beds, which may be very thin (Fig. 26), were interpreted as "storm units" brought offshore by storm surges.

Fossils collected from the black mudstone of the Ostracode Zone in this well yielded two dissimilar faunas: a marine one, consisting of two species of foraminifer and two species of dinoflagellate; and a freshwater one, consisting of two species of freshwater ostracode. However, this apparent contradiction can be reconciled by assuming that the ostracodes came from the graded beds described above, which represent sediments brought in from shallower waters, and that the marine fauna from the black shales is the indigenous offshore assemblage.

Figure 26. Photograph of a thin section of a graded bed found in the black mudstone of the Ostracode Zone in the Empire Jenner well. Freshwater ostracode shells were probably transported and deposited in these graded beds. P, pyrite (opaque); Ch, chert; O, ostracode shell.

One of the thicker graded beds has been examined in thin section and is illustrated in Figure 26. It consists largely of quartz sand, large chert fragments and a few broken shells, including one problematic ostracode. A transported origin for the freshwater ostracodes is, therefore, highly probable.

Murphy Red Coulee 3A-5-1-16W4

The Ostracode Zone-Glauconitic Sandstone interval in this well shows an excellent coarsening-upward progradational facies sequence, in the lower part of which (offshore-shoreface), storm sedimentation units consisting of wave-ripple laminated or hummocky cross-stratified, fine grained sandstones alternate with bioturbated black mudstone (Figs. 23C, 25). The sandstones increase upward in thickness from 5 to 30 cm. This sequence is overlain by a thick (15 m), medium grained sandstone displaying low-angle cross-strata at the base (foreshore) and high-angle cross-strata at the top (backshore-dune?). The highly bioturbated mudstone facies of the Ostracode Zone, which lies beneath of the Glauconitic Sandstone, probably records an offshore environment. Although seven species of dinoflagellate from two samples were recorded at horizons 3 to 4 m above the Ostracode Zone (Appendix 2), they belong to a continuous shallowing-upward sequence and reflect shallower depths than those found below them. Therefore, an offshore environment for the underlying Ostracode Zone is suggested both from sedimentological and paleontological evidence.

Other fossil evidence

Figure 27 illustrates the occurrence of marine fossils in the Ostracode Zone and adjacent units in 15 wells (including the three already discussed). It is apparent that occurrences in the Ostracode Zone of foraminifers, echinoid spines, fish teeth, algal matter and dinoflagellates have been recorded in wells located between Townships 20 and 1. Widespread marine conditions during the deposition of the Ostracode Zone may safely be assumed.

The occurrence of dinoflagellates in the top part of the Cut Bank Sandstone in one well (14-2-19-22-W4) close to, but outside the study area, indicates some brackish water influence in the later stages of deposition of that unit. One corroded specimen of agglutinated foraminifer and one specimen of dinoflagellate have been recovered from near the base of the unit (15-15-4-15-W4, Fig. 27) but this occurrence is of dubious import. There is a probability that these fossils have been reworked from the underlying Jurassic strata and no interpretation based on them will be attempted.

PALEOGEOGRAPHIC RECONSTRUCTION

From the data presented in this study, a few brief comments on the paleogeography can be made.

Deville paleogeography

The Deville Formation contains the weathered debris of the Mississippian carbonates that are overlain by bioturbated pyritiferous black mudstones. It represents a karst-derived soil that was probably inundated by sea. As no fossil has been obtained from this unit, a definite marine influence cannot be proved, but the possibility of a basal Mannville marine transgression (in the area north of Township 11) cannot be ruled out.

Cut Bank paleogeography

The location of the Cut Bank Valley, a low-relief plain formed by the Rierdon Shale, and two highlands formed by the Swift sandy sediments, are the major features of the Cut Bank paleogeography (Fig. 28A). The occurrence of a few marine fossils may indicate some estuarine conditions in the northwest.

Ostracode Zone–Glauconitic Sandstone paleogeography

Reconstruction of the paleogeography during the time of deposition of the Ostracode Zone (Fig. 28B) is based on the occurrences of marine fossils (including two occurrences near the base of the Glauconitic Sandstone), and the location of barrier island trends obtained from isopach maps of the Glauconitic Sandstone.

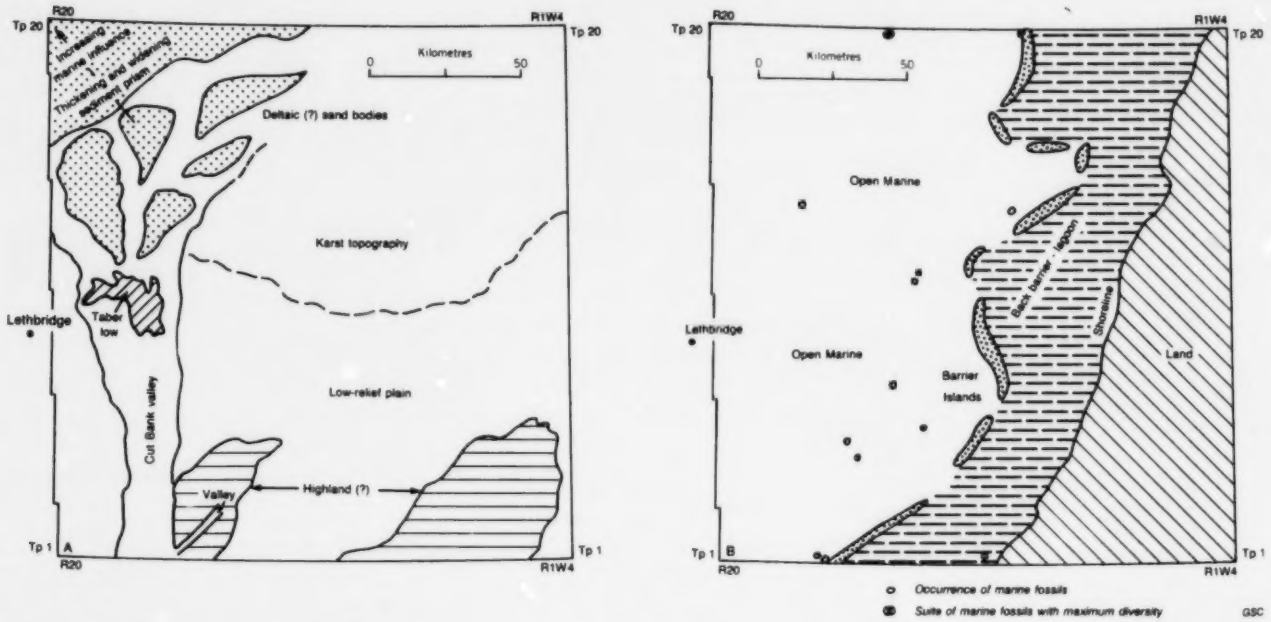


Figure 28. *Paleogeography of the study area during the time of deposition of the Lower Mannville subgroup.*

A. Cut Bank paleogeography. "Taber Low" is a basement depression observed from seismic profiles (Taylor, 1983).

B. Ostracode Zone/Glauconitic Sandstone paleogeography. Location of barrier islands obtained from isopach "thicks" of the Glauconitic Sandstone.

Sixteen occurrences of marine fossils have been plotted in Figure 28B. Location (X) is that of well 10-29-10-13W4, where the most open marine fauna has been obtained. Barrier island (or shoreline) trends of the Glauconitic Sandstone have been obtained from Tilley and Longstaffe (1983) for the northeastern corner of the map area, and from mapping by the author in Township 1, Range 16W4 in the southwest corner. The trend in the southwest corner is continuous with the trend of the Moulton Sandstone (equivalent to the Glauconitic Sandstone) in Montana (Anonymous, 1966; Oakes, 1966). Barrier (shoreline) trends shown between these two locations are speculative.

Tilley and Longstaffe (1983) postulated that the landward side of their barrier trend is to the west. Because location (X), with its fully marine fauna, lies to the west of the trend, the seaward side has been interpreted in the present reconstruction as being to the west and the landward side to the east. A similar reconstruction was also made previously by Jackson (1985, Fig. 21). The sea responsible for deposition of the Ostracode Zone probably extended westward to the Foothills. This possibility will be examined next.

Evidence from the southern Foothills

The five stratigraphic sections presented in Figure 29 have been measured by the author in the southern Foothills. The older view, that the entire Blairmore Group represents continental sedimentation, has been modified by the recent finding of the southward extension of the marine Moosebar tongue in the southern Foothills (Taylor and Walker, 1984). The Clearwater-Moosebar transgression, which is equivalent to the transgression that resulted in the deposition of the Ostracode Zone in the southern Plains, can be traced to the southern Foothills as shown by the discussion below.

In the present study, the following features, which are suggestive of marine influence, have been found in the upper part of the Gladstone Formation:

1. Occurrences of: (i) coarsening-upward sedimentary units that are 2 to 3 m thick, with bioturbated mudstone at the base and wave-ripple laminated, fine grained sandstone at the top (Fig. 29, cols. 3, 5); (ii) rare dinoflagellates (Fig. 29, col. 1); and (iii) rare glauconite grains (Fig. 29, cols. 1, 2, 5).

2. High boron content (>80 ppm) in several shale samples. As most shale samples collected from the Calcareous Member (stratigraphically equivalent to the Ostracode Zone) yielded no microfossils, a geochemical criterion for paleoenvironmental determination was used in this study. Twenty shale samples were analysed for their boron content, which, if carefully studied may

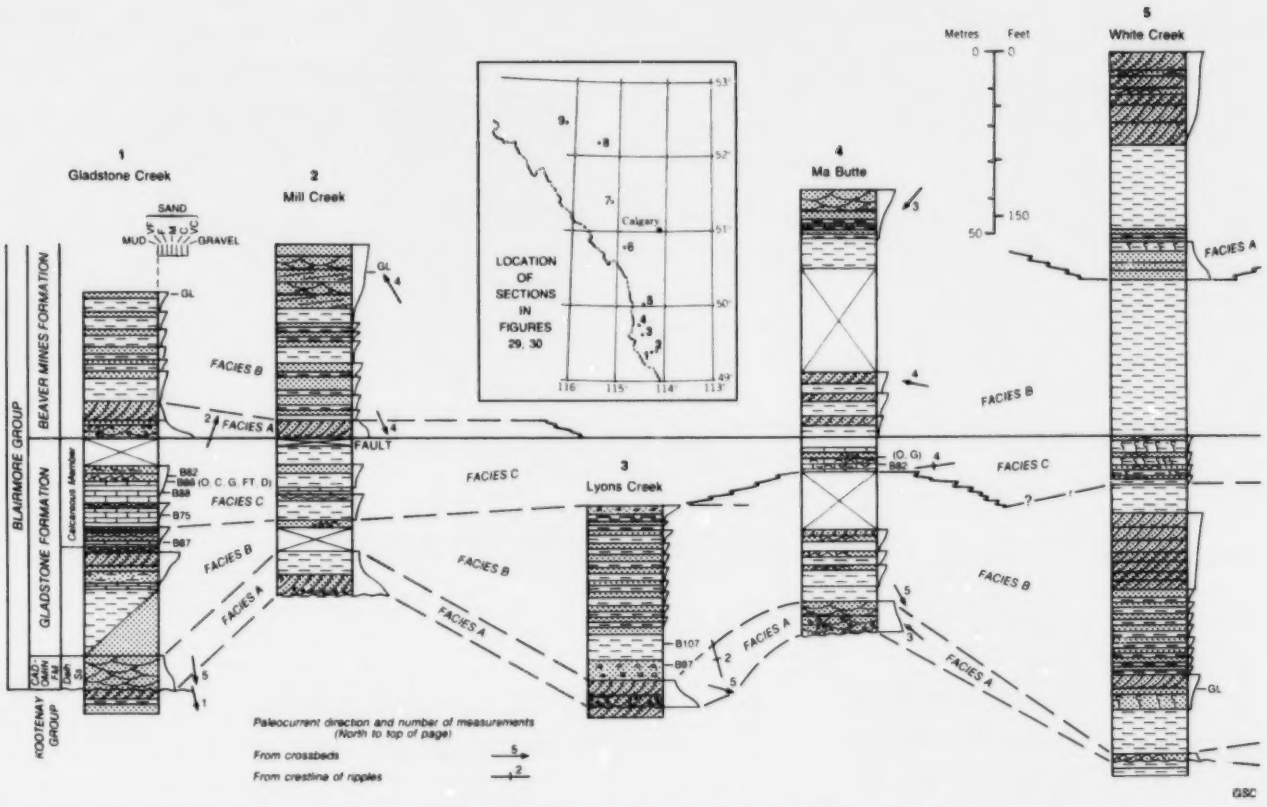


Figure 29. *Five measured cross-sections in the southern Foothills. Marine influence in the Gladstone Formation, especially in its Calcareous Member, is indicated by sedimentary structures such as wave-ripples and graded beds (Lyons Creek), high boron content (Lyons Creek) and marine fossils (dinoflagellates in Gladstone Creek). For legend refer to Figure 10. Inset map shows location of measured sections. B, boron (ppm); C, charophyte; D, dinoflagellate; FT, fish teeth; G, gastropod; GL, glauconite; O, ostracode; A, B . . . Facies (see Figure 30 for description).*

be an indicator of paleosalinity, and thus of paleoenvironment (Hills and Levinson, 1975; Levinson and Ludwick, 1966). Normally, a boron content of 0 to 50 ppm may be considered as indicating fresh water, 50 to 100 ppm, brackish water, and values above 100 ppm, marine water. In the Foothills samples analyzed, one sample (col. 3, Fig. 29) has a value greater than 100, and seven have values between 50 and 100 (cols.1, 4, Fig. 29). Taken together with other evidence, this strengthens the case for a marine depositional environment.

It must be admitted here that irrefutable evidence of a marine origin for these sediments is lacking. Prolific and diverse assemblages of marine fossils have not been found in these rocks. However, all the features described above suggest a marine influence. Based on that postulate a facies model for these stratigraphic units in the Foothills is presented in Figure 30.

This schematic facies diagram (Fig. 30) shows facies relationships in the central and southern Foothills. The diagram has been compiled from the author's data and data from Taylor and Walker (1984) and Wanklyn (1985). Facies C, which coincides with the Calcareous Member (Ostracode Zone) in the Foothills, most probably records a marine transgression, as in the southern Plains.

The southernmost extension of this transgression can be traced to the Great Falls area in Montana, where Burden (1983) found a dinoflagellate assemblage in the Sunburst Member of the Kootenai Group, which is stratigraphically equivalent to the Mannville Group. Extensive bioturbation of the Sunburst Member is also another indication of the marine nature of the unit. Walker (1974), who studied the Kootenai Group in Montana just south of the area studied here, observed the presence of "oscillation and interference ripple marks" and "an abundance of burrowing", and concluded that "were it not for the absence of more positive

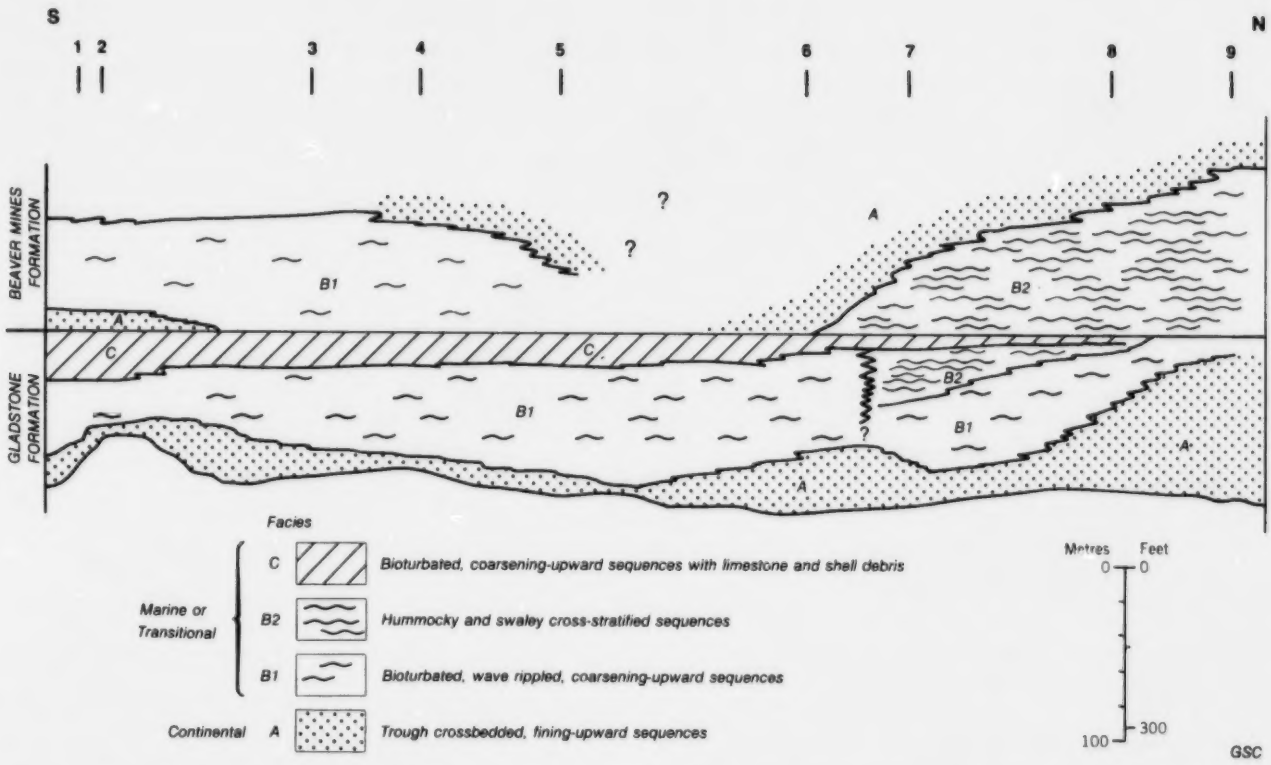


Figure 30. *Interpreted facies relationships in the central and southern Foothills. Presence of rare glauconite grains and dominance of coarsening-upward sequences have been taken as evidence of some marine influence in the upper part of the Beaver Mines Formation. For locations of sections, see inset map in Figure 29. Sections 1 to 5 are from this study; sections 6 and 7 are from Taylor and Walker (1984); and sections 8 and 9 are from Wanklyn (1985).*

evidence for a marine fauna, it would be very tempting to interpret some of these beds as marine''. With the finding of marine flora in them, their marine nature has now been established.

AGE OF THE LOWER MANNVILLE FORMATIONS

As part of this study, a large number (286) of samples from cores were collected and treated in order to extract microfossils (139 for microfauna and 147 for palynomorphs). Unfortunately, the majority of the samples were barren and only a little more than 100 samples yielded any fossils. Out of these, only 53 samples carried fossil assemblages (mostly palynomorphs) from which reliable age data could be derived. No samples from the Deville Formation yielded any microfossils. The distribution of samples in the other formations are as follows:

Glauconitic Sandstone	9
Ostracode Zone	20
Cut Bank Sandstone	3
Swift Formation	8
Rierdon Shale	11
Sawtooth Formation	2
TOTAL	53

Detailed descriptions of the fossil assemblages and discussions of their paleogeological and biostratigraphic implication are beyond the scope of this study and will be done in a future publication. Here, only the broad age ranges of the different formations will be discussed.

The data on the ages of different formations belonging to the Mannville and Ellis groups have been summarized in the correlation chart shown in Figure 31.

A few comments on the age data are necessary here:

1. The age range of the Cut Bank Sandstone is based on three samples only and may have to be revised when more data are available.

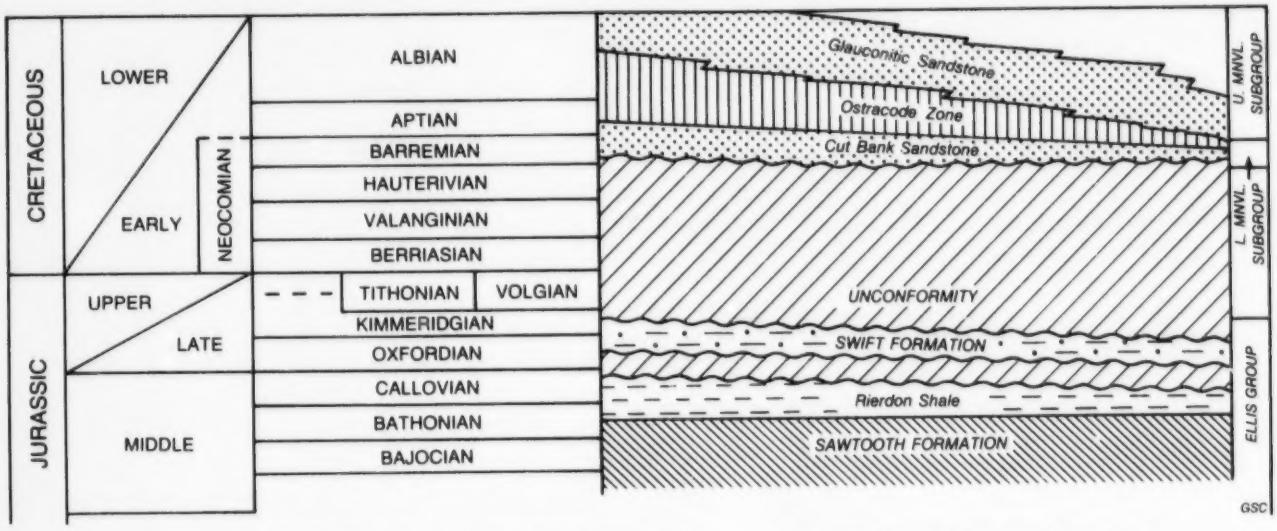


Figure 31. *Correlation diagram showing the age relationships of the different stratigraphic units of the Ellis and Mannville groups.*

2. A part of the Rierdon Shale could be age equivalent to a part of the Swift Formation.

3. There are only two samples from the Sawtooth, and both indicate a Bathonian age. The base of the Sawtooth is possibly much older.

4. The Ostracode Zone and The Glauconitic Sandstone have overlapping ages. Both units are time-transgressive. The diachronous nature of the Ostracode Zone has also been noted by Finger (1983).

The age data presented in Figure 31 both agree and disagree with previously published data. The Oxfordian age of the Swift Formation and the Bathonian age for the Sawtooth is consistent with the data published by Poulton (1983), but he confined the Rierdon Shale to the Bathonian, and stated that the Callovian was not represented in the Ellis Group. In contrast, Figure 31 shows that the Rierdon Shale represents the Callovian and extends into the Oxfordian.

According to the present study (Fig. 31), the base of the Lower Mannville subgroup is as old as Barremian. Burden (1983) found, on the basis of palynomorphs, that the oldest age established for the base of the Mannville (in the Lower McMurray of the Steepbank River in northern Alberta) was late Valanginian. Pocock (1980) considered the whole of the Lower Mannville subgroup to be Aptian. The Barremian age is based on the palynomorph assemblage from only a few samples and more data are required to corroborate it.

The age of the Ostracode Zone in central Alberta has been designated as late Aptian to early Albian by Finger (1983); the equivalent strata of the Calcareous Member in the Foothills, as "slightly older than Early Albian" by McLean and Wall (1981); and the Calcareous member of Montana as late Barremian to early Albian by Burden (1983). The age range of the Ostracode Zone (Fig. 31) encompasses the whole span. No published age of the Glauconitic Sandstone is known to this author and, therefore, the Aptian-Albian age shown in Figure 31 remains uncorroborated.

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APPENDIX 1

List of cores examined

Series no.	Location of Well	Interval in feet (m)	Formation, member, or group
1	07-29-01-08W4	3069-3114 (935.4-949.1)	SNB/SWFT
2	04-05-01-09W4	2997-3020 (913.5-920.5)	SNB
3	10-19-01-09W4	2817-2847 (858.6-867.8)	SNB
4	11-34-01-09W4	2971-2991 (905.6-911.7)	SNB
5	10-09-01-10W4	2887-2935 (880.0-894.6)	SNB/SWFT/ RRD
6	06-36-01-10W4	2810-2824 (856.5-860.8)	SWFT
7	06-01-01-11W4	2956-2971 (901.0-905.6)	SNB
8	06-11-01-13W4	2535-2556 (772.7-779.1)	SNB/RRD
9	03-13-01-13W4	2570-2618 (783.3-798.0)	SNB/SWFT
10	07-18-01-14W4	2340-2400 (713.2-731.5)	OST
11	11-23-01-15W4	2344-2374 (714.5-723.6)	
12	04-02-01-16W4	2405-2430 (733.0-740.7)	CTB/RRD
13	08-03-01-16W4	2430-2486 (740.7-757.7)	MLTN/SNB
14	3A-05-01-16W4	2469-2506 (752.6-763.8)	MLTN
15	10-05-01-16W4	2440-2477 (743.7-755.0)	MLTN
16	02-04-01-17W4	2650-2811 (807.7-856.8)	MLTN/CTB/ ELLS
17	14-33-01-19W4	3440-3550 (1048.5-1082.0)	GLCN/OST/ CTB
18	11-12-03-17W4	2965-3025 (903.7-922.0)	OST/TAB
19	16-12-03-17W4	3060-3120 (932.7-951.0)	TAB
20	01-13-03-17W4	2959-2980 (901.9-908.3)	TAB
21	16-13-04-17W4	3060-3120 (932.7-951.0)	OST/TAB/ RRD
22	01-13-04-20W4	3520-3580 (1072.9-1091.2)	UMNVL
23	15-15-04-15W4	2843-2873 (866.5-875.7)	BSL/SWFT
24	12-36-04-15W4	2800-2878 (853.4-877.2)	TAB/SWFT/ RRD
25	11-06-06-16W4	*3166-3182 (965.0-970.0)	TAB
26	14-33-04-11W4	2870-2971 (874.8-905.6)	SNB/RRD
27	11-21-05-15W4	2910-2990 (887.0-911.4)	SNB
28	07-31-06-12W4	2835-2912 (864.1-887.6)	SNB/RRD
29	10-05-06-13W4	2931-2991 (893.4-911.7)	OST/SNB/ RRD
30	04-32-06-14W4	3020-3073 (920.5-936.7)	SNB
31	15-17-07-14W4	2785-2846 (848.9-867.5)	BSL
32	01-20-07-14W4	2790-2840 (850.4-868.7)	GLCN/BSL
33	07-20-07-14W4	2823-2910 (860.5-887.0)	RRD/CTB/ OST/GLCN
34	14-20-07-14W4	3051-3102 (929.9-945.5)	GLCN
35	05-29-07-14W4	3020-3073 (920.5-936.7)	BSL/RRD
36	10-36-09-10W4	3089-3130 (941.5-954.0)	BSL/RRD/ SWTH
37	15-03-10-10W4	2970-3022 (905.3-921.1)	UMNVL/GLCN
38	04-27-10-12W4	2958-2972 (901.6-905.9)	ELLS
39	16-06-10-13W4	3041-3052 (926.9-930.2)	BSL/ELLS
40	06-13-10-17W4	3208-3289 (977.8-1002.5)	CTB

Series no.	Location of Well	Interval in feet (m)	Formation, member, or group
41	10-27-10-17W4	3286-3345 (1001.6-1019.6)	TAB
42	16-30-11-12W4	3002-3024 (915.0-921.7)	GLCN/SNB
43	07-31-11-12W4	2915-2974 (888.5-906.5)	SWTH
44	08-31-11-12W4	2939-2969 (895.8-905.0)	OST/BSL
45	02-06-12-13W4	2903-3003 (884.8-915.3)	SNB
46	04-29-13-13W4	3135-3180 (955.5-969.3)	OST/SNB
47	06-36-14-06W4	2454-2504 (748.0-763.2)	UMNVL
48	03-10-14-09W4	3039-3089 (926.3-941.5)	GLCN/OST/ SNB
49	07-22-14-13W4	3160-3206 (963.2-977.2)	OST/BSL/ PKCH
50	04-34-14-13W4	3165-3211 (964.7-978.7)	OST/BSL
51	10-03-18-21W4	4660-4750 (1420.3-1447.6)	OST/BSL
52	05-19-20-01W4	2770-2801 (844.2-853.7)	UMNVL
53	06-29-20-06W4	*3333-3392 (1016.0-1034.0)	UMNVL
54	06-09-20-07W4	3094-3124 (943.1-952.2)	GLCN
55	06-10-20-07W4	3065-3125 (934.2-952.5)	GLCN
56	12-28-20-08W4	3096-3149 (943.7-959.8)	GLCN
57	12-32-20-08W4	3020-3121 (920.5-951.3)	GLCN/OST
58	10-10-20-11W4	3244-3269 (988.8-996.4)	OST/SNB
59	02-03-20-12W4	3267-3323 (995.8-1012.9)	OST/SNB
60	10-11-20-12W4	3200-3326 (975.4-1013.8)	GLCN/OST/ BSL
61	10-29-20-13W4	3332-3386 (1015.6-1032.1)	OST/BSL/ DTL
62	06-20-20-15W4	3149-3207 (959.8-977.5)	UMNVL

*measured in metres

Abbreviations:

UMNVL = Upper Mannville interval overlying Glauconitic Sandstone

GLCN = Glauconitic Sandstone
MLTN = Moulton Sandstone
} equivalent terms

OST = Ostracode Zone

SNB = Sunburst Formation
CTB = Cut Bank Formation
TAB = Taber Formation
BSL = Basal Quartz
} all included under Cut Bank Sandstone in this study

DTL = Detrital Zone or Member — Deville Formation of this paper
ELLS = Ellis Group
SWFT = Swift Formation
RRD = Rierdon Shale
SWTH = Sawtooth Formation
PKCH = Poker Chip Shale

As well as the 62 cores examined, data from 93 core logs from the AGAT report were used for construction of the facies map (Fig. 20) and one cross-section (Fig. 18b).

APPENDIX 2

Micropaleontology
(J.H. Wall)

Formation	Well location, depth, and comments	GSC loc. no.
Cut Bank Sandstone	Trans Canada W.G.C. No. 1 15-15-4-15W4; 2840 feet (865.6 m)	C-119836/2840
	No microfossils obtained except for a single, incomplete, arenaceous foraminifer.	
Cut Bank Sandstone	Conrad Province No. 75-36-C 12-36-4-15W4; 2831 feet (862.9 m)	C-119835/2831
	Foraminifera: *Lenticulina audax* Loeblich and Tappan; three *L.* sp.; very small, one	
	Ostracoda: *Bythocypris*(?) sp.; one to two genus-genera indeterminate; partially embedded or incomplete specimens.	
	Seeds: *Microcarpolithes* sp. (form genus); illustrated by McLean and Wall (1981, Pl. 6, figs. 8, 9) from the Gladstone Formation of the Alberta Foothills.	
	Gastropoda: conchs displaying a relatively high spire.	
	Age: Jurassic, based on the assumption that the *L. audax* is indigenous to the assemblage and has not been reworked or incorporated into it through picking contamination.	
	Environment: the assemblage does not appear to be a natural one but rather a mixture of marine and nonmarine elements. The foraminifera are marine, the seeds probably nonmarine, and the ostracodes and gastropods could be either. The sample may possibly have been taken at a level that reflected a change in biotope, or some extraneous material was included in the original core sample.	
Ostracode Zone	Grid Oil Grand Forks 8-31-11-12W4; 2950 feet (899.2 m)	C-136253/2950
	Foraminifera: *Ammodiscus francisi* (Wall); abundant.	
	Charophyta: *Aclistochara* or *Stellatochara* sp.; two flattened or incomplete gyrogonites with intercellular ridges.	
	Pisces: one small tooth.	
	Age: a Jurassic age is indicated on the basis of the common occurrence of *A. francisi* in the Shaunavon Formation of Saskatchewan (Bajocian-Bathonian). Similar charophytes are present in the same formation. However, both of these organisms are the sort that might be expected to recur at higher levels in a similar environment. Therefore, an Early Cretaceous age cannot be ruled out.	
	Environment: marine, shallow, probably marginal and brackish, as is shown by the large population of a single species of arenaceous foraminifera and by the presence of charophytes, which generally are associated with a freshwater habitat but do occur in some modern brackish water environments.	

Formation	Well location, depth, and comments	GSC loc. no.
Ostracode Zone	Empire State et al. Jenner 12-32-20-8W4; 3107 feet (947 m)	C-108301/3107
	Ostracoda: *Candona* (?) *stirlingensis* Loranger *Cypridea* sp., with short spines	
	Foraminifera (very rare, pyritized): *Haplophragmoides* (?) sp.; one specimen *Ammobaculites* (?) sp., incomplete; one specimen.	
	Affinity indeterminate: smooth, polished, subovate to rounded entities, possibly of coprolitic origin and associated with macrofossils.	
	Age: Early Cretaceous, probably Aptian.	
	Environment: dominantly freshwater, possibly with slight brackish water influence. Interpretation is based on the overwhelming dominance of these ostracode species, which are typical nonmarine forms. A marine influence may be indicated by the very few foraminifera present, but their extreme rarity and poor preservation suggest that they may not have been part of the living assemblage.	
Ostracode Zone	K.S. Sinclair Millicent 10-29-20-13W4; 3333 feet 1015.9 m)	C-108305/3333
	Foraminifera: *Reophax* sp. cf. *R. minuta* Tappan; one specimen. *R.* sp.; one specimen *Haplophragmoides* sp.-spp.; dominant *Ammobaculites* sp., small with short uncoiled portion; two to three specimens *Trochammina* sp. ex gr. *T. uniatensis* Tappen; one compressed specimen *Gaudryina* sp. cf. *G. tailleuri* (Tappan); two specimens *G.* sp.; one specimen *Arenobulimina* spp.; two species with one specimen each *Anomalina* (?) sp.; one specimen.	
	Echinoidea: spine; one specimen.	
	Affinity indeterminate: shell fragments and other debris; rare.	
	Age: Early Cretaceous, possibly Albian but assemblage not sufficiently diagnostic for accurate placement.	
	Environment: shallow marine.	

Palynology
(A.R. Sweet)

Formation	Well location, depth, and comments	GSC loc. no.
Cut Bank Sandstone	14-2-19-22W4; 1474 m (4836 ft.)	C-104750/4836
	Angiosperm pollen: *Clavatipollenites minutus* Brenner 1963 *C. hughesii* Couper 1958 (?) *Liliacidites textus* Norris 1967 *Stellatopollis* sp.	

Formation	Well location, depth, and comments	GSC loc. no.
	Spores: *Cicatricosisporites australensis* (Cookson) Potonié 1956 *C. pseudotripartitus* (Bolkhovitina) Dettmann 1963 *Concavissimisporites variverrucatus* (Couper) Brenner 1963 *Crybelosporites stylosus* Dettman 1963 *Lycospora cretacea* Pocock 1962 *Reticulatisporites castellatus* Pocock 1962	
	Algal cysts: thin walled dinoflagellate cysts, dominantly *Palaeoperidinium cretaceum* Pocock 1962; common.	
	Comment: preservation and recovery excellent.	
	Age: all the species of angiosperm pollen are monocolpate. This type of angiosperm pollen first appears in the Barremian. The earliest published record of tricolpate pollen in Alberta is from the middle Albian although it has been recorded from the lower Albian elsewhere. Using the known local range, the absence of tricolpate pollen from these assemblages suggests a pre-middle Albian age. Therefore, an age within the range of Barremian to early Albian is indicated. The spores present support this age but are not necessarily diagnostic of it.	
	Paleoenvironment: the presence of dinoflagellates in the samples from 1429 m and 1474 m suggest a marine influence (an increase in salinity) at these horizons. Of the two samples, the one from 1429 m most probably indicates a fully marine environment based on the higher diversity within the dinoflagellate assemblage.	

Palynology
(D.J. McIntyre)

Formation	Location of outcrop section and comments	GSC loc. no.
Gladstone Formation, Calcareous Member, (39.7 m above contact with Kootenay Formation) P2643-11	Mill Creek, Alberta; 49°24′30″N, 114°10′W; NTS 82 G/8	C-119763
	Corroded plant tissue is abundant. Some corroded conifer pollen and fern spores are present, as are rare, unidentified dinoflagellates.	
	Environment: probably nearshore marine.	

	Well location, depth, and comments	GSC loc. no.
Ostracode Zone	Empire State et al. 12-32-20-8W4; 3107 feet (947 m)	C-108301/3107
	Pollen and spores Conifer pollen abundant *Gleicheniidites senonicus* Ross *Cicatricosisporites australiensis* (Cookson) Potonié Dinoflagellates *Muderongia asymmetrica* Brideaux *Pseudoceratium restusum* Brideaux	
	Age: Aptian to middle Albian.	

Formation	Well location, depth, and comments	GSC loc. no.
	Environment: probably very nearshore marine.	
Ostracode Zone	10-29-20-13W4; 3333 feet (1015.9 m)	C-108305/3333
	Abundant material, probably of algal origin.	
	Environment: probably shallow marine, possibly tidal flat conditions.	

Palynology
(E.H. Davies [Bujak Davies Group])

Formation	Well location, depth, and comments	GSC loc. no.
Glauconitic Sandstone	Murphy Red Coulee 3A-5-1-16W4; 2493 feet (759.9 m)	C-119826/2493
	Dinoflagellates: *Muderongia asymmetrica.*	
	Miospores: *Taxodiaceaepollenites hiatus.*	
	Age: Aptian–early Albian.	
	Paleoenvironment: inner neritic.	
Glauconitic Sandstone	3A-5-1-16W4; 2506 feet (763.8 m)	C-119826/2506
	Dinoflagellates: *Escharisphaeridia* sp. *Meiourogonyaulax deflandrei* (derived) *Muderongia asymmetrica* *Pseudoceratium* sp.	
	Miospores: *Alisporites grandis* *Cicatricosisporites augustus* *Cicatricosisporites hughesi* *Cicatricosisporites potomacensis* *Clavatipollenites minutus* *Corollina torosa* *Eucommidites minor* *Parvisaccites amplus* *Plicatella silvestris* *Stereisporites antiquasporites* *Taxodiaceaepollenites hiatus*	
	Age: the association of *Clavatipollenites minutus*, and *Muderongia asymmetrica*, which are known from Aptian and lower Albian sediments, along with *Parvisaccites amplus*, which is known from Aptian and older sediments, indicates an (?late) Aptian age for this sample.	
	Paleoenvironment: the presence of the brackish water dinoflagellates *Pseudoceratium* sp. and *Muderongia asymmetrica*, along with numerous miospores and abundant black coaly kerogen and cuticle, indicates a transitional marine depositional environment.	

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